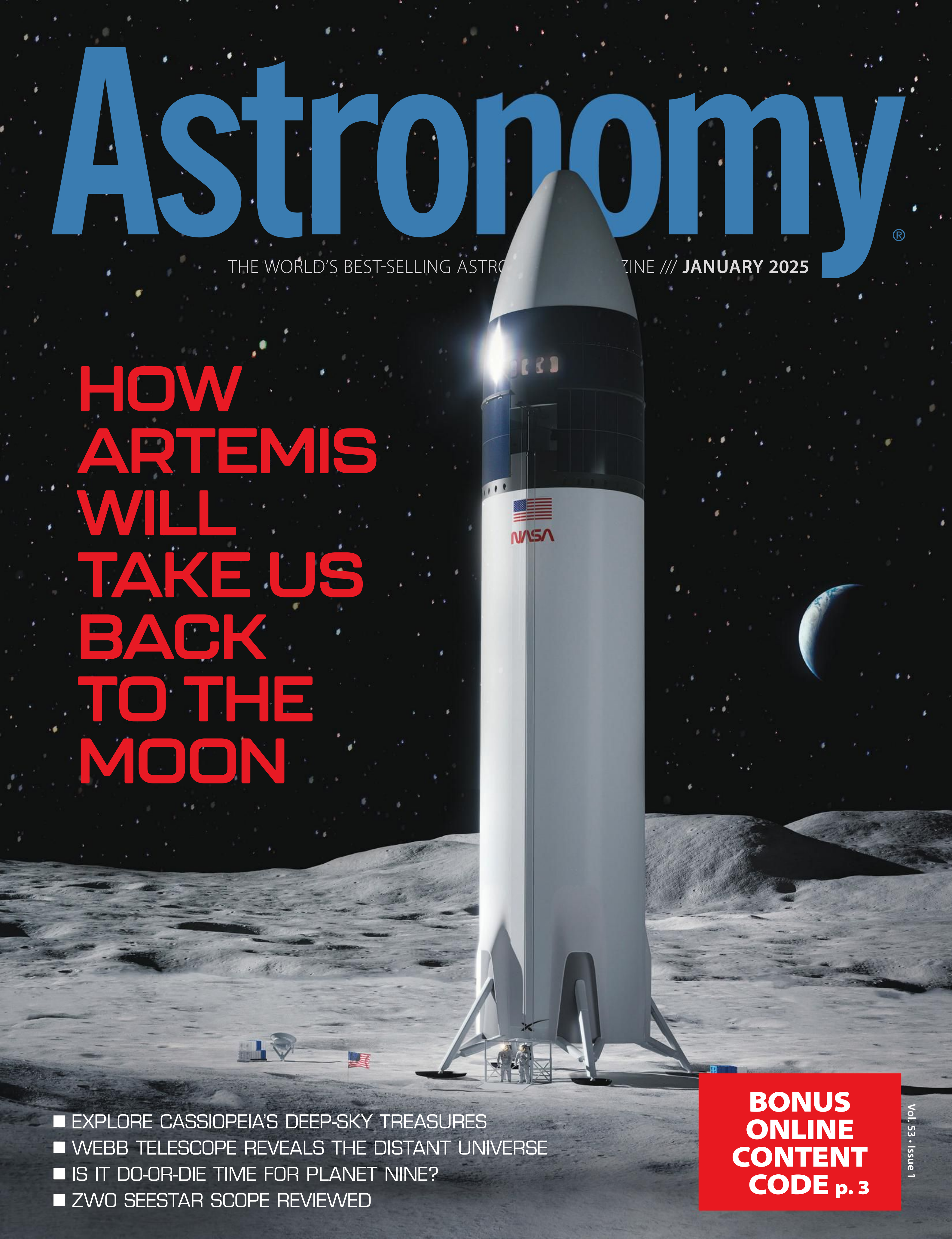

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- ZWO SEESTAR SCOPE REVIEWED

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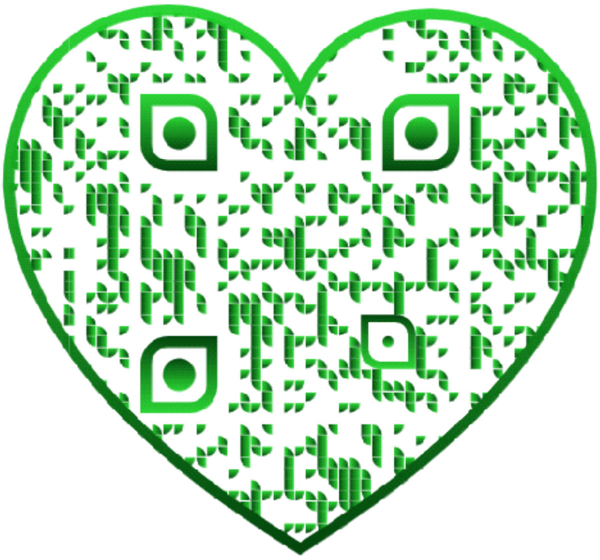
Vol. 53 • Issue 1



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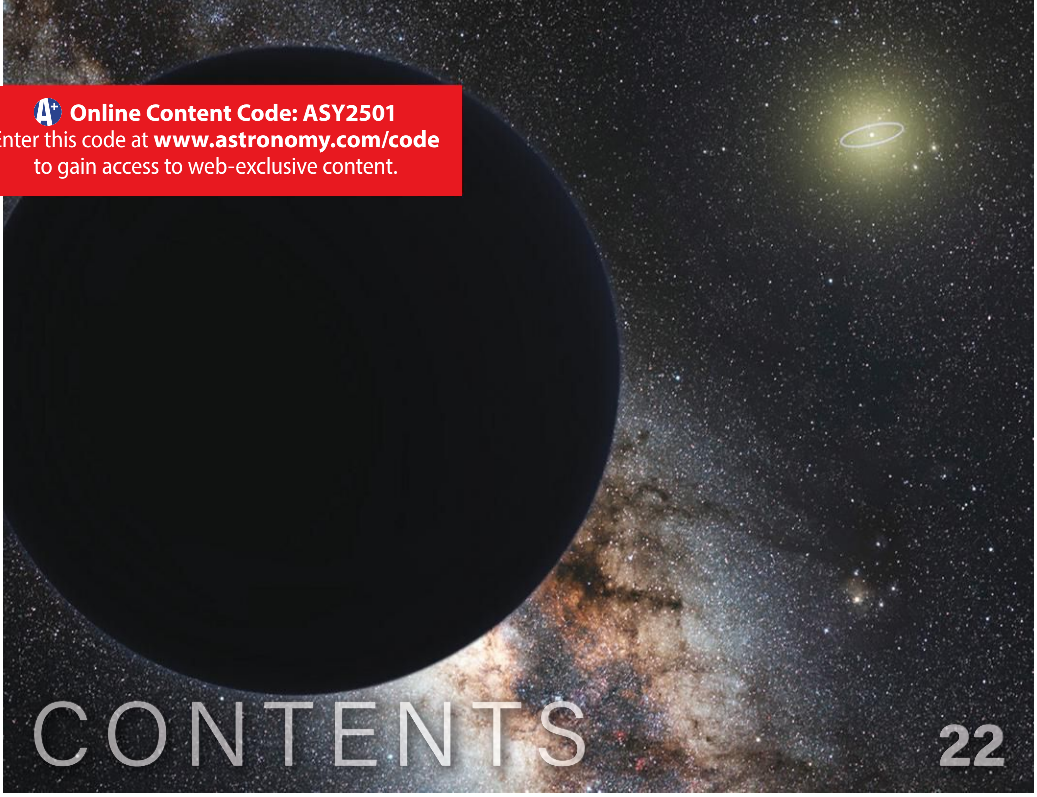

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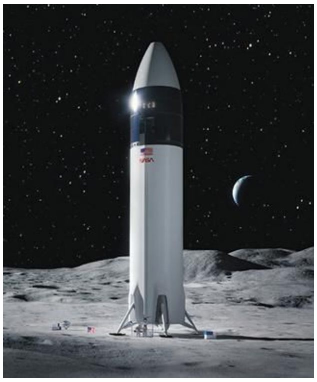

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The Starship HLS stands on the lunar surface in this artist's concept, celebrating the ushering in of a new age of exploration. NASA

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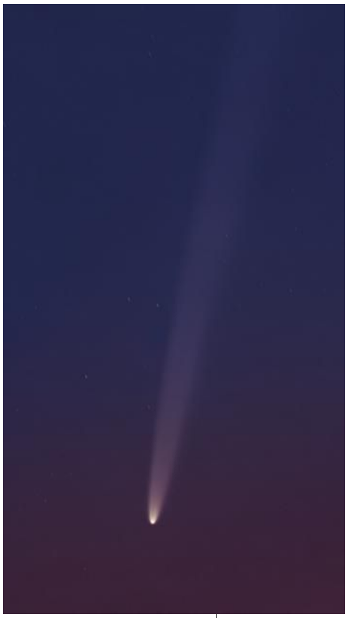
FROM THE EDITOR

# Universe discovered


Chris Schur recorded Comet 2023 A3 Tsuchinshan-ATLAS during the first week of October 2024.
CHRIS SCHUR

I want to tell you about a new product that we at *Astronomy* are creating. Universe, Discovered is a weekly newsletter that I will be writing from now on, and it will contain highlights of all the most important stories in the world of astronomy that you should be aware of during the week.

Our Firecrown crew has been extremely supportive and enthusiastic toward *Astronomy*, and we have some exciting things coming down the road. The team behind Universe, Discovered is a joy to work with, and includes our Editorial Director Meg Scarbrough, Vice President of Media Operations Julia Becker, Email Marketing Manager Marie Eich, and others.

I assembled my first Universe, Discovered newsletter during the week of Oct. 7, 2024, and it represented an exciting moment for science results, spacecraft activity, night sky events, and more. The first offering provided a good sampling of the kind of materials we will bring to your attention every week, distributed in every way we can realistically envision. A few days before the first newsletter went out, I was way down south on Easter Island with a group of *Astronomy* readers who traveled to see the long annular solar eclipse of Oct. 2. We also had a breathtaking predawn view of Comet 2023 A3 Tsuchinshan-ATLAS, a bright naked-eye object that dazzled everyone in our group. Needless to say, the newsletter reported on this welcomed celestial visitor.

I'll also report on new and noteworthy discoveries. For instance, the week of the first newsletter, astronomers announced a surprising finding, a galaxy in the very early universe that shows a well-ordered, seemingly mature disk. Astronomers have believed that very young galaxies are disordered messes, far from evolving a stately disk component. Such mysteries keep the flood of new data absorbing, and keep astronomers busily working at their jobs.

Keep a lookout for Universe, Discovered. You can sign up for it on Astronomy.com. It'll be great fun bringing you the latest and greatest discoveries, sky events, and more each week in this amazing cosmos we inhabit.

Yours truly,

David J. Eicher
Editor

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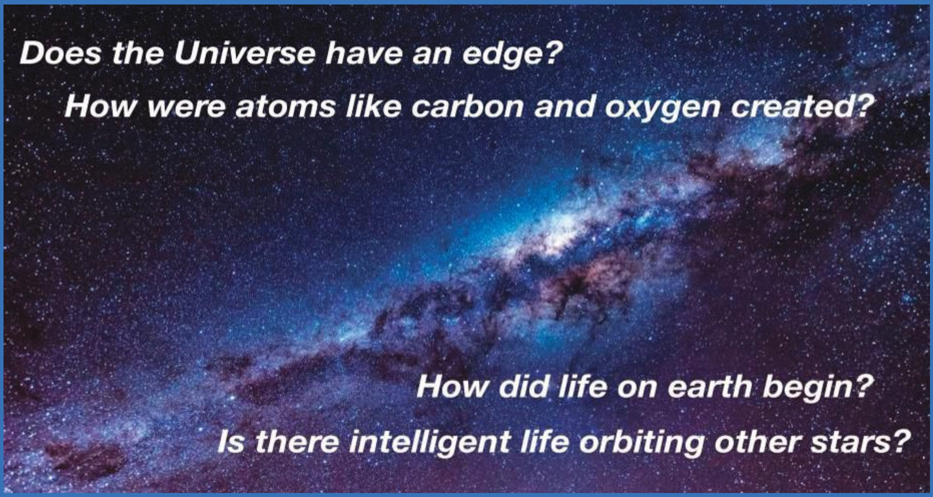
Does the Universe have an edge?
How were atoms like carbon and oxygen created?
How did life on earth begin?
Is there intelligent life orbiting other stars?

Dr. George Roush will explore

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SECRET SKY

Nature's eclipse reactions

Total solar eclipses trigger all kinds of behavior in the animal kingdom.

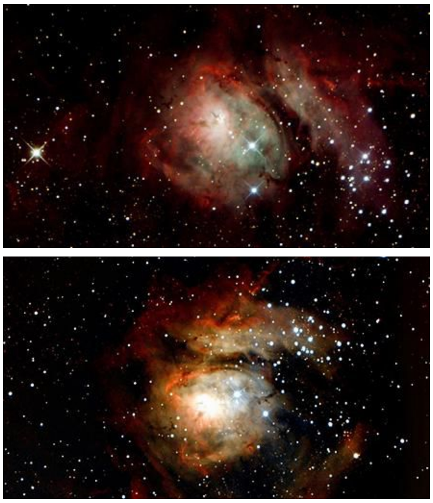
Animals took their usual position for sleeping.

## Natural reaction

Thanks for the call for nature's eclipse reactions during the April 8 eclipse ("Nature's Eclipse Reactions," September 2024). I saw the eclipse from a marvelous site in Mansfield, Ohio, at the former estate of an industry baron, now Kingwood Center Gardens. Lushly landscaped, the estate is in a hollow populated by a variety of animals, including peacocks that roam at large. We had only high cirrus clouds at our site, which allowed for a pretty good view of totality.

Not long before totality, a flock of mallard ducks marched past. All but the alpha male went to feed in a watered garden area away from their duck pond. The male settled in the grass to wait, but soon cocked his head to the side, gazing upward for some time. Surely he was looking at the Sun, which then was in eclipse. He kept this up, then called for the rest of the flock and they retired to somewhere else away from the pond. I did not see them during totality. When totality came, the peacocks, in different areas of the estate, all began screaming. I've never heard a peacock alarm before; it sounds like a cat yowling. To hear them from different directions was unlike anything I've experienced. —**Earle Spamer,** Maple Shade, NJ

*We welcome your comments via email to* **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*



The top photo shows M8 taken with only a camera, while the bottom photo includes the Starizona Nexus.

GEORGE FISCHER

## Nexus in action

I enjoyed the review of the Starizona Nexus you published in October's issue. I observe and image with a 12-inch Dobsonian telescope on an equatorial platform using electronic-assisted astronomy. I use a ZWO ASI183MC camera, so due to the smaller sensor size, coma is not an issue. However, I wanted to achieve a larger field of view with sharper stars — plus in the future I am looking to upgrade to a larger sensor, where coma would become apparent. Considering these factors, I decided to purchase the Nexus.

The Nexus performs flawlessly with perfect stars, making it well worth the investment. —**George Fischer,** Queen Creek, AZ

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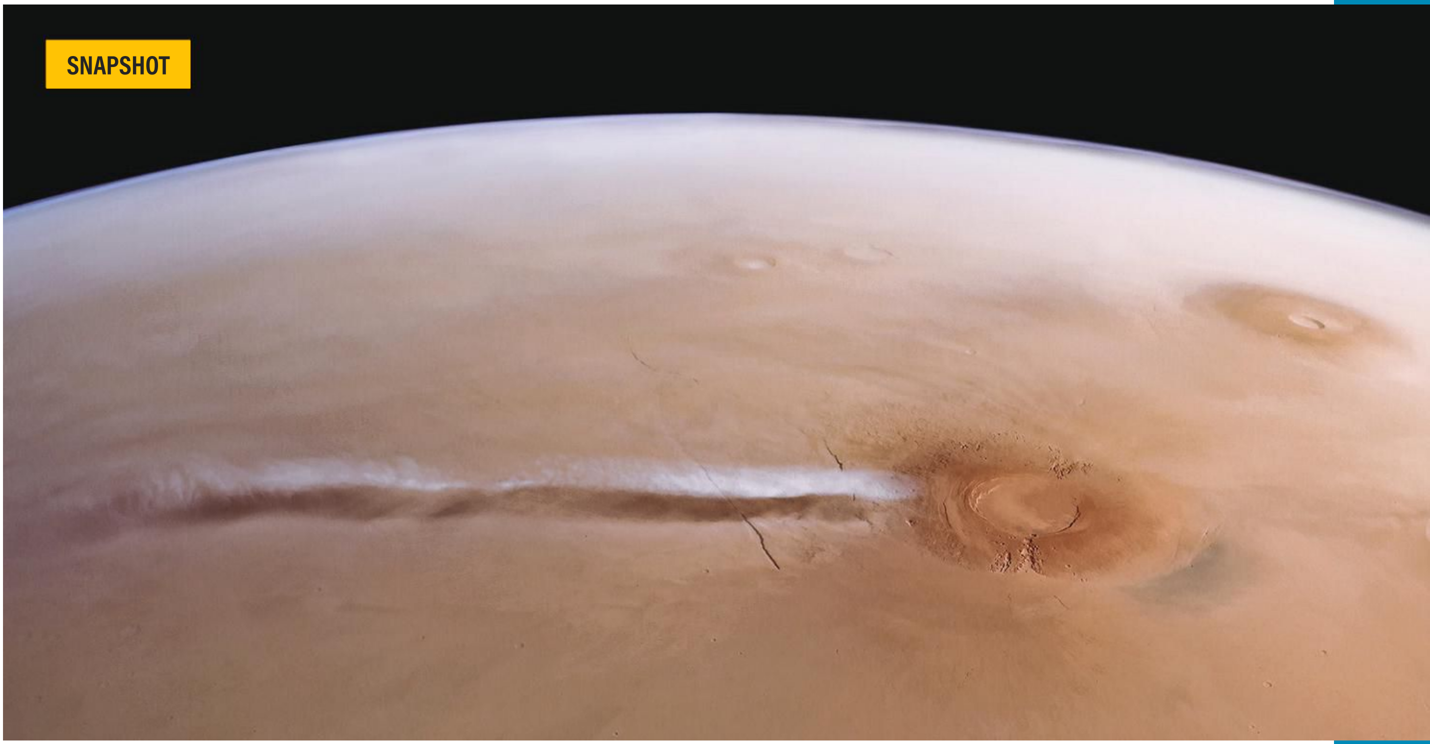
# QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH

SNAPSHOT



# MARS CLOUD ATLAS

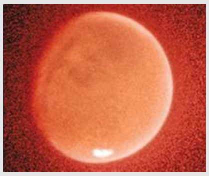
## A public database showcases unique weather on the Red Planet.

Every day for 2½ months around the southern summer solstice, a white, water-ice cloud stretches some 1,100 miles (1,770 kilometers) across the martian surface. The Arsia Mons Elongated Cloud, shown here, develops early in the morning and dissipates by noon, created by updrafts that develop as wind sweeps across the 11-mile-high (18 km) Arsia Mons volcano on the Tharsis Plateau.

The sprawling feature is one of many included in a newly released cloud atlas created by the German Aerospace Centre in Berlin, featuring 20 years of images. The photos, taken by the High Resolution Stereo Camera aboard the European Space Agency's Mars Express orbiter, showcase the many types of water- and carbon-dioxide-ice clouds, as well as clouds of dust lofted into the thin atmosphere, that form across the face of Mars.

Explore the Cloud Atlas for yourself at https://hrscteam.dlr.de/public/data.php. —ALISON KLESMAN

## » HOT BYTES



**GREAT ESCAPE**
Data from Hubble and the MAVEN Mars orbiter show that hydrogen from broken-up water molecules escapes more quickly when Mars is closer to the Sun, which could reveal how the Red Planet lost its water over time.

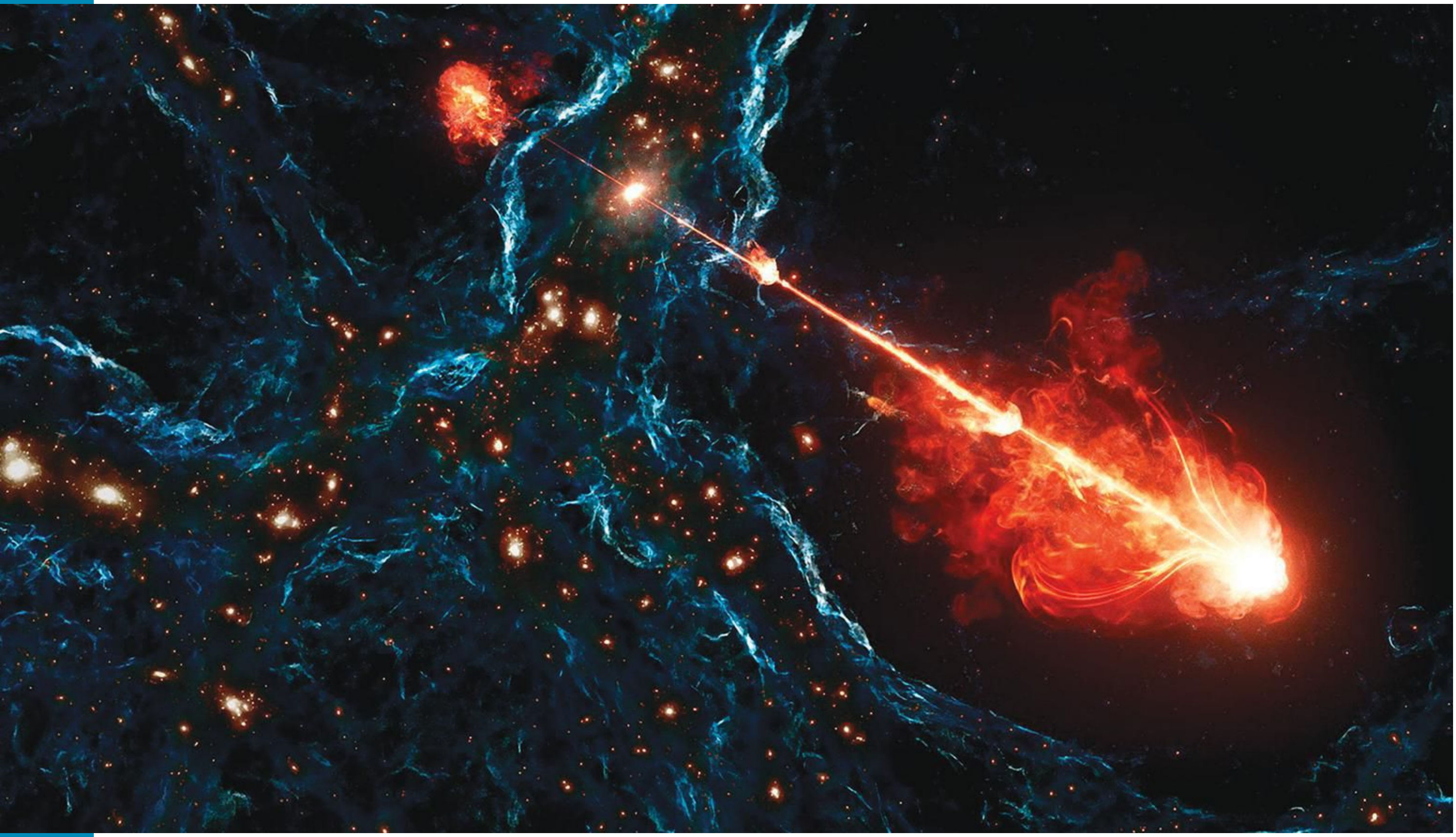
**PRIVATE PARTY**
SpaceX's Polaris Dawn mission, which flew from Sept. 10–15, successfully completed the first commercial spacewalk Sept. 12, as the craft reached some 455 miles (732 km) above Earth.

**HOT AIR**
JWST spotted a galaxy 1 billion years after the Big Bang whose gas outshines its stars. It could serve as a bridge to understanding how the first stars gave rise to their successors.

ESA/DLR/FU BERLIN/A. COWART. BOTTOM FROM LEFT: NASA, ESA, STSCI, JOHN T. CLARKE (BOSTON UNIVERSITY), IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI); SPACEX; NASA, ESA, CSA, STSCI, A. CAMERON (UNIVERSITY OF OXFORD)

# GIANT BLACK HOLE JETS STRETCH DEEP INTO THE COSMIC VOID

Spanning millions of light-years, the jet system might show how black holes shaped the early universe.



**COSMIC REACH.** This artist's illustration shows Porphyrion, the largest black hole jet system ever observed (top center). Its jets are so large that they stretch out into the voids between superclusters of galaxies, which are connected by the blue-tinged cosmic web. E. WERNQUIST/D. NELSON (ILLUSTRISTNG COLLABORATION)/M. OEI

Like a dragon breathing a long spout of fire, a black hole in the distant universe is spewing plumes of energy into the cosmos, forming jets that span 23 million light-years. That's 140 times the width of the Milky Way, enough to influence the evolution of the universe at scales previously unheard of.

The find, announced Sept. 18 in *Nature*, is named Porphyrion, after a mythological Greek giant who warred with the gods for control of the cosmos. It is twice as large as the previous record-holder, which was also found by the new study's lead author, Martijn Oei of Caltech and Leiden University in the Netherlands, and colleagues in 2022.

## PEERING INTO THE PAST

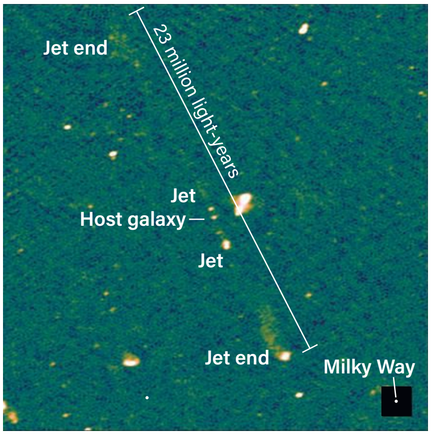
Porphyrion was discovered within survey data from Europe's LOFAR (LOw Frequency ARray) radio telescope. Radio waves are the best way to search for the massive jets that form when material falls into the supermassive black hole at the center of a massive galaxy.

While the LOFAR survey will eventually cover the entire Northern Hemisphere, Oei's team had access to only about 15 percent of the sky. They uncovered more than 11,000 jets spanning over a megaparsec (3.26 million light-years) in length. Before this, astronomers knew of a few hundred.

The team searched Porphyrion's location with additional telescopes and found a galaxy roughly 70 billion solar masses (about the size of M82), viewed when the universe was a little over 6 billion years old, roughly half its current age.

### A LONG REACH

Until now, all megaparsec-scale jet systems were found later in the universe's 13.8-billion-year history, in older elliptical galaxies. While black holes can pour out enormous energy in jets — more than 100 galaxies' worth of stars — it takes hundreds of millions of years for those jets to reach record-breaking lengths. Younger, star-forming galaxies were thought too unstable to sustain jets for so long.



**A TRUE GIANT.** This image from the LOFAR radio telescope shows the extent of the Porphyrion jet system, which stretches some 140 times the width of the Milky Way. A much smaller, separate jet system appears as a bright blob to the upper right of Porphyrion's host galaxy. LOFAR COLLABORATION/MARTIJN OEI (CALTECH)

But Porphyrion exists much earlier in the universe's history, when the universe was livelier but more compact. So Porphyrion's reach extends not only past its host, but two-thirds of the way into the cosmic void, the space between superclusters of galaxies. This means its reach was truly cosmological, on a scale with the largest structures in the cosmos.

And it is only the biggest system discovered, with tens of thousands more smaller jets also found. If systems like Porphyrion turn out to be common, they may have had a much larger impact on the universe's evolution than previously thought. When the jets from a supermassive black hole push past the galaxy itself, their influence doesn't stop. In addition to heating the material within their host and stopping star formation, they can magnetize the wispy material between galaxies and galaxy clusters, a phenomenon astronomers thought might be a relic of the Big Bang itself. But it is now possible that black hole jets are the architects of this process.

LOFAR should reveal tens of thousands more colossal jet systems as it continues to scan the skies. With thousands already identified, and machine learning to speed up the search on new maps, there will be ample fodder for future investigations. — KOREY HAYNES

# The nest of the Swan

ESO/VVVX SURVEY

M17 is known as the Swan Nebula for its distinctive visual appearance. But a profile of poultry is barely recognizable in this near-infrared image of the star-forming region, which lies 5,500 light-years distant in Sagittarius. Taken by the European Southern Observatory's Visible and Infrared Survey Telescope for Astronomy (VISTA), located on Chile's Cerro Paranal, this image reveals the region's massive veins of dark dust, which serve as material for new stars. The bright region at the center is lit by the open cluster NGC 6618 — the hatchlings of this stellar breeding ground. — MARK ZASTROW

## QUICK TAKES

### BOWLED OVER

Ganymede was smacked 4 billion years ago by an asteroid 190 miles (300 km) across that reoriented which side of the moon faces Jupiter, according to an analysis of the impact site and surrounding furrowed terrain published Sept. 3 in *Scientific Reports*.

### ACQUISITION HISTORY

The spin of the Milky Way's central supermassive black hole — which is not aligned with the galactic disk — could be explained by a merger with another black hole from the center of the Gaia-Enceladus dwarf galaxy, which the Milky Way swallowed 9 billion years ago, says a Sept. 6 study in *Nature Astronomy*.

### POLLUTING THE BRAIN

Exposure to nighttime light pollution is associated with increased prevalence of Alzheimer's disease in those under the age of 65, a study reported Sept. 5 in *Frontiers in Neuroscience*. The association is stronger than factors including alcohol abuse and obesity.

### MARK YOUR CALENDAR

Models published Sept. 24 in *The Planetary Science Journal* suggest that debris from the Double Asteroid Redirect Test's (or DART) impact on the asteroid Dimorphos could reach Earth in May 2034 and produce the first human-made meteor shower.

### CLASH CALLED OFF?

The Milky Way and the Andromeda Galaxy (M31) — previously thought to merge in around 5 billion years — may avoid a collision. A study submitted to the *arXiv* preprint server July 31 reported their trajectories could be altered by nearby M33 and the Large Magellanic Cloud.

### SETTING SAIL

NASA's Europa Clipper mission launched on a five-year voyage to its namesake moon of Jupiter on Oct. 14. The craft will investigate Europa from orbit to see if conditions in its subsurface ocean could support life. — M.Z.

# NUCLEAR BOMBS COULD DEFLECT ASTEROIDS, LAB TESTS SUGGEST

**DEFLECTING KILLER ASTEROIDS** with nuclear weapons has long been the stuff of science fiction. But thanks to a new experiment, that scenario has taken a step closer to reality.

Yes, just as in the movie *Armageddon*, scientists believe that nuclear weapons could be tools to protect our planet. However, detonating a nuclear weapon directly on an encroaching asteroid could risk fracturing the asteroid instead of redirecting it, raining many smaller but still deadly meteoroids onto Earth.

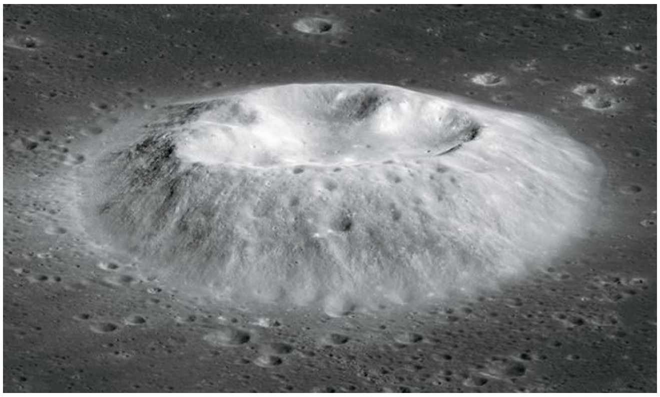
A leading proposal is to instead set off a nuclear bomb at some distance from the asteroid to increase the odds of steering the asteroid off a collision course.

To test this method, researchers at Sandia National Laboratories in Albuquerque, New Mexico, used a powerful X-ray beam to blast tiny chips of quartz and silica.

The X-rays themselves imparted some momentum to the chips, but a larger push came from a different mechanism: The X-rays heated the surface of the material, causing it to vaporize. The material then expanded away from the surface, much like a rocket or jetpack, shoving the chip in the opposite direction at speeds of up to 160 mph (260 km/h).

Scientists observed the same

# The Moon's volcanoes may be much younger than thought



**CONE OF SILENCE.** The volcano Mairan T stands over 2,000 feet (600 m) tall above the plains of Oceanus Procellarum. NASA/GSFC/ARIZONA STATE UNIVERSITY

» Researchers from the Chinese Academy of Sciences in Beijing have reported evidence that the Moon was volcanically active just 123 million years ago, a geologic blink of an eye — a finding that has the potential to rewrite lunar history.

The results come from an analysis of lunar samples returned in 2020 by the Chang'e 5 mission, and published Sept. 6 in *Science*. The craft plucked 3.82 pounds (1,731 grams) of lunar soil from Oceanus Procellarum (Ocean of Storms), delivering the first haul of Moon samples since the Russian Luna 24 mission in 1976.

From the samples, the team meticulously separated about 3,000 glass beads ranging between 0.0008 to 0.016 inch (20 to 400 micrometers) in size. Laboratory analysis revealed that the majority of the beads were generated by the extreme heat of an asteroid impact. However, the team identified three beads as volcanic in origin through their chemical composition and sulfur isotopes.

Uranium-lead dating showed these three volcanic beads were only 123 million years old, give or take 15 million years. The beads also contained a high abundance of thorium and rare Earth elements, further suggesting that the heat to produce them came from the lunar mantle.

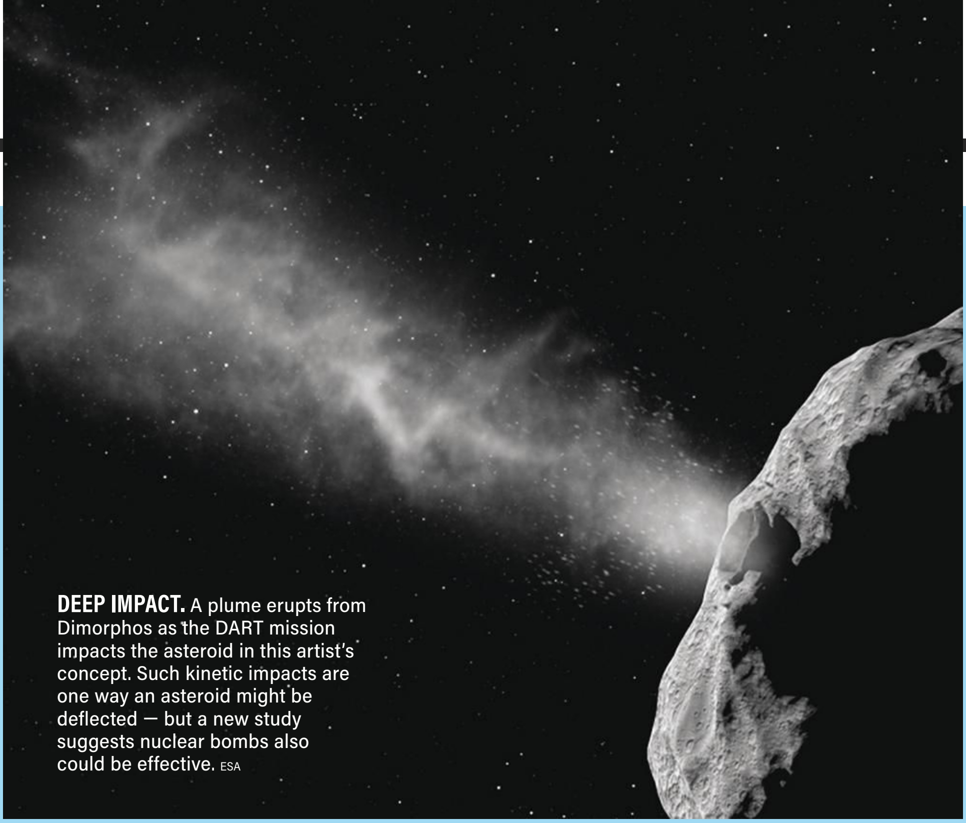
Planetary scientists have long known that the Moon hosted ancient volcanoes — the very face of the "man in the Moon" is formed by dark volcanic basalt plains in low-lying impact basins. But those sheets were deposited during a billion-year period of high volcanic activity between 3 billion and 3.8 billion years ago. And researchers have assumed the Moon has been volcanically inactive for the past billion years.

The finding of volcanic samples just 123 million years old is stunning, and implies that volcanoes have been erupting on the Moon for essentially its entire 4.6-billion-year existence — as recently as when the dinosaurs roamed Earth.

The possibility is buttressed by previous observational hints. For instance, irregular mare patches are regions with a surface surprisingly devoid of impact craters, suggesting an age of less than 100 million years.

This raises the question of whether the Moon is still producing magma today. Can internal radioactive elements provide enough heat for magma chambers to still exist deep within the Moon's mantle? Modeling studies will be needed to provide insight to this question. – ROBERT REEVES effect when NASA's Double Asteroid Redirection Test (DART) mission crashed into Dimorphos in 2022 — the flying ejecta propelled the asteroid further than the spacecraft itself.

While the experiment used chunks of material only half an inch (1.2 centimeters) across, the team's calculations suggest that the basic idea is powerful enough to successfully deflect asteroids up to 2.7 miles (4.4 kilometers) across, making their research, published Sept. 23 in *Nature Physics*, a significant step toward practical planetary defense. –K.H.



**DEEP IMPACT.** A plume erupts from Dimorphos as the DART mission impacts the asteroid in this artist's concept. Such kinetic impacts are one way an asteroid might be deflected — but a new study suggests nuclear bombs also could be effective. ESA

# SHORT-LIVED ORGANICS HINT AT CERES' HABITABILITY

NASA's Dawn mission revealed that the dwarf planet Ceres may have — or may once have had — an ocean. Now, new research provides evidence that the world might also hold the right stuff for life.

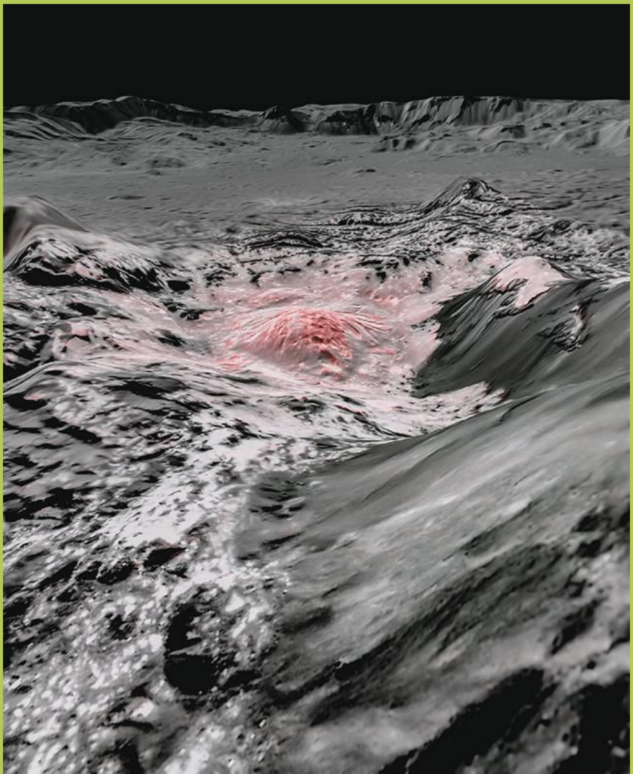
In a Sept. 25 paper in *Science Advances*, researchers present evidence that long-chain aliphatic organics (AOs) — hydrocarbons that often form lipids (fats) — may have formed within Ceres and come to the surface via cryovolcanism.

Prior to this study, scientists knew there were AOs on Ceres, but whether they had been deposited by meteorites or formed there was unclear. The latter idea bolsters the case that Ceres was once an oceanic world, as similar compounds are found on worlds like Enceladus. The relative abundance of these chemicals on Ceres also seemed too high to have come from meteorites alone.

AOs degrade quickly, within about 10 million years. That means the AOs on Ceres' surface must have appeared recently. Additionally, the AOs are found near sites that have evidence of plumelike activity. "Ceres is a geologically active world. … [It] can be considered a still evolving body," says lead author Maria Cristina De Sanctis, a planetary scientist at INAF-Istituto di Astrofisica e Planetologia Spaziali in Italy.

Her team compared Dawn data with a re-creation of Ceres-like conditions in a lab. There, AOs were subjected to the radiation expected in space at Ceres' distance from the Sun. Based on the observed breakdown of the AOs, the team now believes AOs buried beneath the surface were pushed up from the deep ocean of Ceres and exposed over time, rather than coming from above.

If so, this supports the case that Ceres' ocean could have supported life. "In particular, the high quantity of AO and the kind of AO … increase the potential of Ceres in terms of habitability," De Sanctis says. — JOHN WENZ



**SALTY CLUES.** This false-color image of Ceres' Occator Crater shows where briny water from below the surface was pushed up and evaporated, leaving bright salt deposits (pink). NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

# ARTEM

# EXPLAINED

Three launch systems and two landers from Boeing, SpaceX, and Blue Origin are all part of the complicated puzzle of NASA's Artemis program.

BY MARK ZASTROW

**SIXTY-FIVE YEARS AGO,** the USSR shocked the world by sending the first robotic emissary from Earth to the Moon. The September 1959 impact of Luna 2 on northeastern Mare Imbrium was a stunning achievement, reaching the Moon less than two years after the launch of Sputnik 1 ushered in the Space Age. The event helped ignite the technological firestorm now known as the Space Race between the U.S. and the USSR.

# IS

The Starship HLS stands like a giant 1950s science-fiction spaceship in this artist's concept, spanning 30 feet (9 m) wide and reaching 160 feet (50 m) above the Moon's surface. NASA

The U.S. responded to the lunar challenge with a flurry of robotic and human explorers. Less than 10 years after Luna 2 reached the Moon, Neil Armstrong took his "one small step for mankind" on the Sea of Tranquility.

But just as Apollo reached its stride and the scientific exploration of the Moon began in earnest, politics ended the greatest technological effort in the history of humankind and the Moon faded from our dreams.

Now, in the first decades of the 21st century, the Artemis program to return to the Moon has taken root. The U.S. and international partners have formulated plans and hardware that will return humans to the Moon within the next several years.

The current, publicly available Artemis timelines remain very optimistic, but they must be tempered with the program's extraordinary complexity and ambition. Perhaps unsurprisingly, Artemis is facing repeated development delays, although none of the technological obstacles appear to be showstoppers.

The real question is: When will new footprints appear on the Moon?

## The Artemis plan

In contrast to the Apollo program's singular push to the Moon, with modules for an entire mission all stacked atop a single Saturn V rocket, the Artemis program will use multiple vehicles developed by both NASA and private industries. These include NASA's Space Launch System (SLS) with a Boeing-built core stage, the SpaceX Super Heavy launcher, and Blue Origin's New Glenn rocket. SpaceX and Blue Origin each also are building a crewed lunar lander. Other hardware includes lunar spacesuits and autonomous rovers to carry astronauts and cargo near the Moon's south pole.

The uncrewed Artemis 1 mission has already flown, in 2022. The Artemis 2 mission in 2025 will use the SLS rocket to send a crew of four on a looping flight around the Moon aboard an Orion spacecraft. The first Artemis lunar landing comes with Artemis 3; that and future landing missions will employ a complex scheme of multiple rocket launches and combinations of three different crewed spacecraft. The development of two independent lunar landing systems is intended to foster competition and also serve as an insurance policy if technical issues delay the development of one of the vehicles.

TOYOTA
JAXA
TOYOTA

The Japan Aerospace Exploration Agency (JAXA) has commissioned Toyota to build a rover with a sealed and pressurized crew cabin. Toyota has dubbed the vehicle the Lunar Cruiser. TOYOTA

# ARTEMIS 1

**AFTER A DELAY OF SIX YEARS,** the uncrewed Artemis 1 mission launched Nov. 16, 2022, and validated the Space Launch System rocket and Orion spacecraft systems. The 25-day test flight included six days in lunar orbit and approached within 80 miles (130 kilometers) of the lunar surface. After splashdown and recovery off the coast of Baja California, Mexico, it was discovered that the Orion spacecraft's heat shield suffered higher than expected erosion during atmospheric reentry. This, along with a testing failure of the Orion environmental system, has delayed the flight of the crewed Artemis 2 mission while these issues are analyzed and corrected.

The Moon and Earth loom in the background of this image taken from an uncrewed Orion capsule on the Artemis 1 mission. NASA

## SUITING UP FOR THE MOON

**ONE OF THE MANY DRIVING FACTORS** determining when Artemis will alight on the Moon is the spacesuits to be used by the astronauts. Apollo astronauts worked for up to three days on the Moon using spacesuits developed in the late 1960s. Long-term comfort and wear from the extremely abrasive lunar dust quickly became issues. Artemis will initially spend six days on the Moon, eventually extending to 30-day excursions, and the factors that surfaced during Apollo must be addressed for future explorations.

NASA's new lunar suits are being developed by startup company Axiom Space, headed by seasoned ex-NASA managers. Fashion giant Prada is lending expertise with stitching skills and working with exotic materials. The design of the new suit, known as the Axiom Extravehicular Mobility Unit, or AxEMU for short, is particularly challenging. Unlike the Apollo suits that operated only in daylight and were designed to keep the astronauts cool, the Axiom suits must operate for up to two hours inside permanently shadowed craters near the south pole. Here temperatures can dip to less than 30 kelvins (minus 405 degrees Fahrenheit [minus 243 degrees Celsius]). The engineering challenges encountered by Axiom can be solved, but they have slowed progress in developing the next generation of lunar spacesuits. *— R.R.*

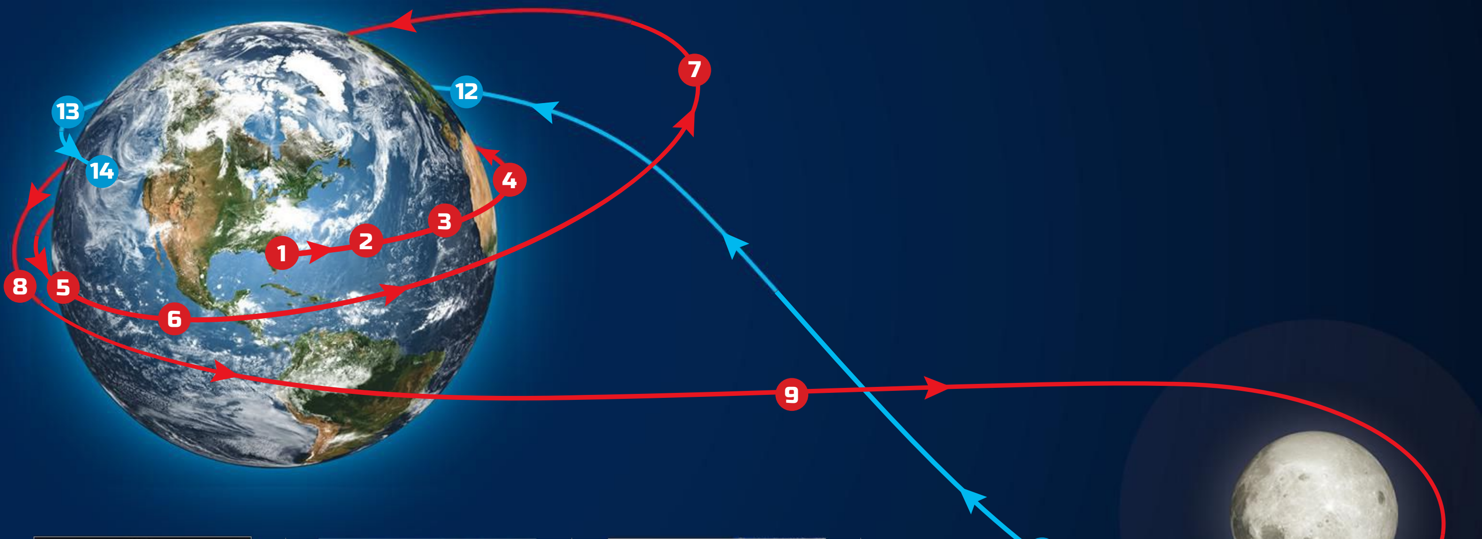
RIGHT: The AxEMU suits are designed to make it easier for astronauts to kneel down and collect samples from the Moon, as shown in testing at NASA's Johnson Space Center. AXIOM SPACE

BELOW: Axiom and Prada's lunar spacesuits were revealed Oct. 16 at the International Astronautical Congress in Milan. PRADA/AXIOM SPACE

# ARTEMIS 2

**EXPECTED TO FLY NO EARLIER THAN SEPTEMBER 2025,** Artemis 2 will use the SLS to send a crew of four aboard an Orion spacecraft on a 10-day mission looping within 4,600 miles (7,400 km) of the Moon. The crew consists of Commander Reid Wiseman, Pilot Victor Glover, and mission specialists Christina Koch and Canadian astronaut Jeremy Hansen. Koch will be the first woman to travel to the Moon, and Hansen will be the first non-American to make the journey. The quartet have spent a total of 660 days in space on long-duration missions to the International Space Station and have 12 spacewalks between them.

Before departing for the Moon, Artemis 2 will enter a high-altitude 24-hour Earth orbit to check out the Orion spacecraft systems. After separating from the SLS upper stage, the crew will take manual control, turn Orion around, and approach the upper stage in a simulated docking to see how the craft handles in close quarters. Then Orion will turn around and light its Service Module engine, setting off for the Moon.



**1** Launch from Kennedy Space Center, Florida. NASA

**2** Solid rocket boosters, fairings, and launch abort system jettisoned. ROEN KELLY AFTER NASA

**3** Core stage main-engine cutoff and separation. ROEN KELLY AFTER ESA AND NASA

**4** Perigee raise burn to low Earth orbit.

**5** Apogee raise burn to high Earth orbit.

**6** Orion separates from ICPS and performs proximity operations demo. ROEN KELLY AFTER ESA AND NASA

**7** Perigee raise burn.

**8** Trans-lunar injection burn.

**9** Four-day trip to the Moon on a free return trajectory.

**10** Lunar flyby 6,479 miles (10,427 km) above surface.

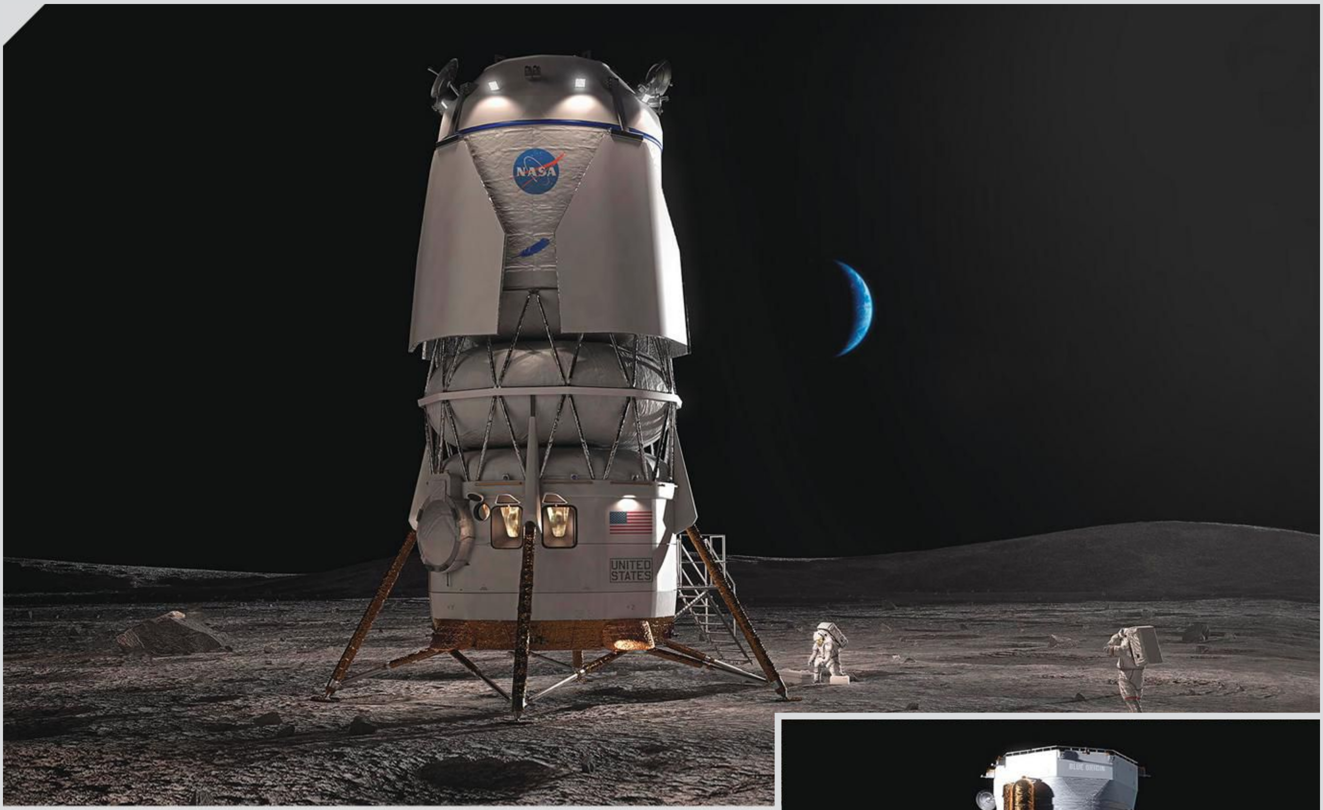
**11** Four-day return trip to Earth.

**12** Crew Module separates from Service Module. ROEN KELLY AFTER NASA

**13** Crew Module reenters atmosphere. ROEN KELLY AFTER NASA

**14** Splashdown in the Pacific Ocean.

BACKGROUND ILLUSTRATION AND INSETS UNLESS OTHERWISE STATED: *ASTRONOMY*: ROEN KELLY



## SPACECRAFT FOR LUNAR EXPLORATION

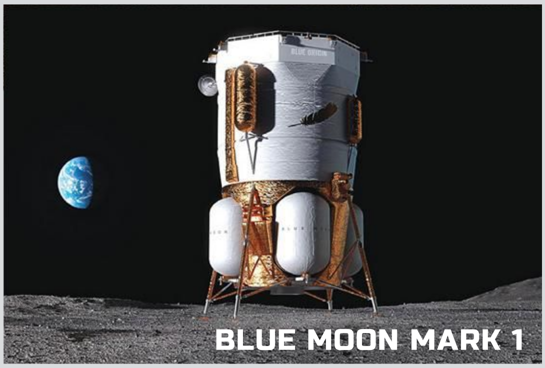
**ARTEMIS WILL UTILIZE FOUR DIFFERENT SPACECRAFT TO RETURN TO THE MOON.**

The cone-shaped Orion spacecraft, resembling an enlarged Apollo Command Module, will be launched by the SLS and carry four astronauts into lunar orbit to rendezvous with a lunar lander. Orion will be buttressed by the European-built Service Module, which will provide power, propulsion, and life support for the Orion.

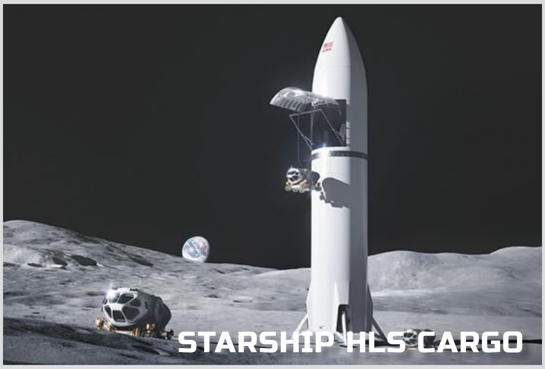
Starship HLS will be based on the current Starship undergoing Earth-orbit testing. But as it will never reenter Earth's atmosphere, it will be devoid of external heat shielding and aerodynamic control flaps. It will also feature five solar panels that extend from midship, while the ship's white coating will prevent the Sun from heating the cryogenic propellants. Heavy braking during the lunar approach with be done with the HLS's six tail-mounted, powerful Raptor engines. But to prevent them from stirring up dust and debris and potentially causing damage, they will be shut down near the lunar surface and the HLS will alight using less powerful thrusters higher up on the HLS body. The HLS will also be equipped with an airlock and elevator system to transport crew and cargo to the lunar surface nearly 100 feet (around 30 meters) below the HLS's habitable area.

Blue Origin's Blue Moon Mark 2 (above) is expected to land crews of up to four astronauts on the Moon beginning with Artemis 5. The craft features an airlock to allow access to the lunar surface without depressurizing the crew compartment. A smaller, single-use, cargo-only precursor, Mark 1, will be capable of delivering 3.3 tons (3,000 kilograms) of supplies anywhere on the Moon. A demo flight of the Mark 1 lander could launch later in 2025 and would seek to perform a pinpoint landing on the Moon's surface within 328 feet (100 m) of a designated target.

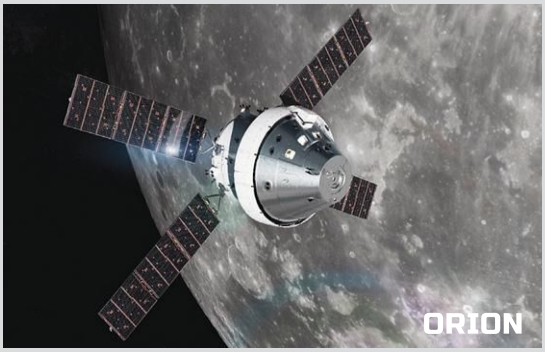
Cargo variants of Starship HLS and Blue Moon Mark 2 are also planned. Starship's cargo capacity is targeted at 100 tons (90,700 kg), though this depends on the performance of the Super Heavy booster. The Mark 2 cargo transport will deliver 22 tons (20,000 kg) of supplies to the lunar surface when configured to be reusable and 33 tons (30,000 kg) on a one-way trip. — *R.R.*



BLUE MOON MARK 1

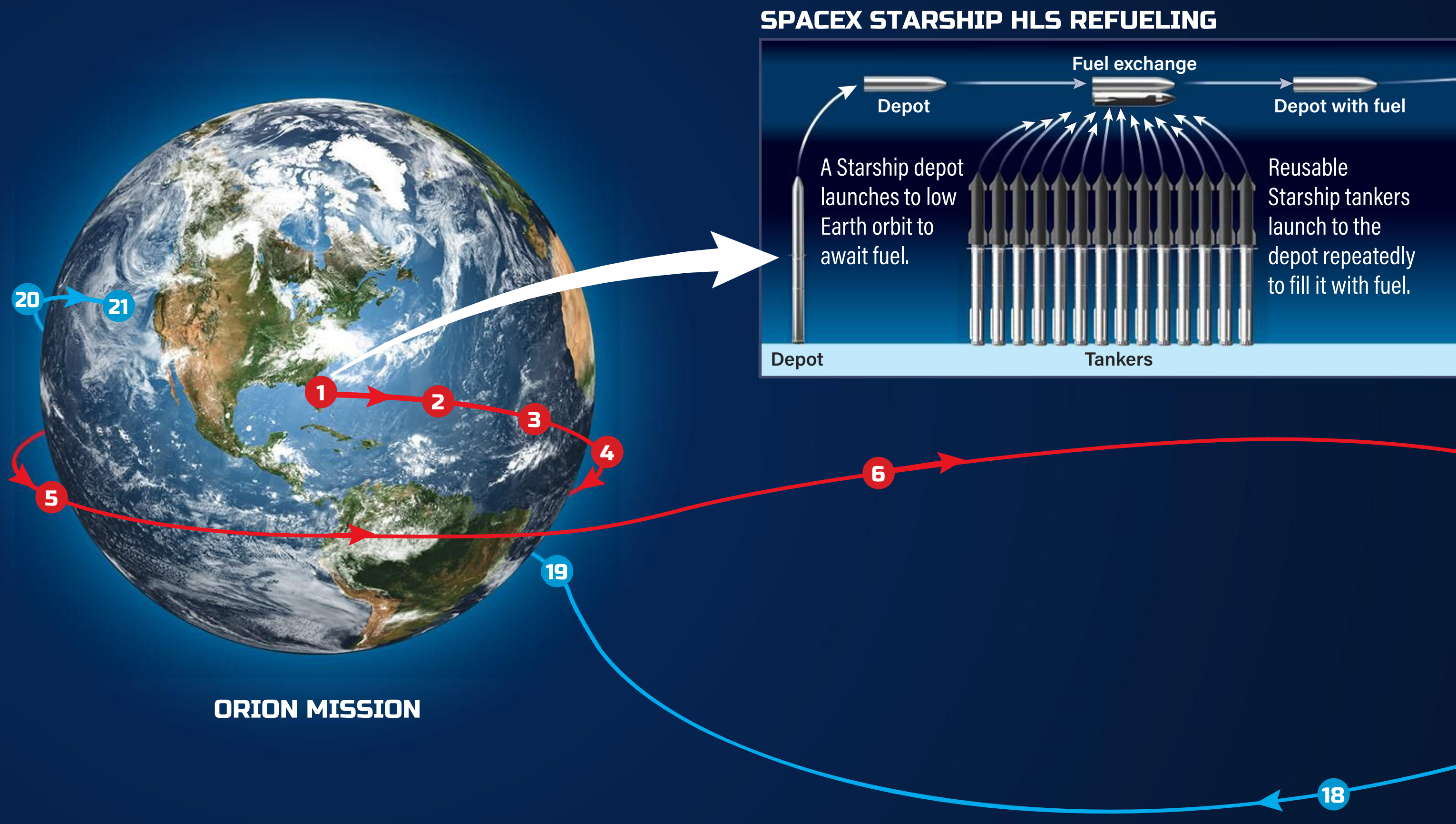


STARSHIP HLS CARGO



ORION

FROM TOP: BLUE ORIGIN; BLUE ORIGIN; NASA; LOCKHEED MARTIN


SPACEX STARSHIP HLS REFUELING
Fuel exchange
Depot
Depot with fuel
A Starship depot launches to low Earth orbit to await fuel.
Reusable Starship tankers launch to the depot repeatedly to fill it with fuel.
Depot
Tankers
20
21
1
2
3
4
5
6
19
18
ORION MISSION

# ARTEMIS 3

**FOR THE INITIAL ARTEMIS 3 LUNAR LANDING MISSION** — the first planned crewed landing on the Moon since Apollo — the SpaceX Starship Human Landing System (HLS) will be placed in lunar orbit, where it will loiter for up to 100 days awaiting the arrival of the crew aboard an Orion spacecraft.

Getting the Starship to the Moon will involve a complex scheme of refueling spacecraft in orbit. First, a fuel-depot version of Starship will be placed in orbit using the SpaceX Super Heavy booster. Next, a series of up to 20 reusable tanker spacecraft launched by the Super Heavy booster will fill the fuel depot with 2 million pounds (910,000 kg) of liquid methane and liquid oxygen. The Starship HLS will subsequently launch, refuel from the depot, then boost to lunar orbit.

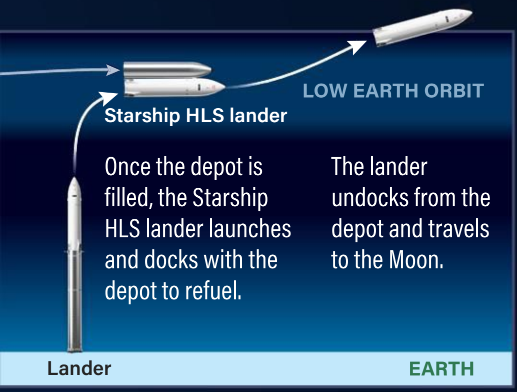
The crew of four astronauts will launch separately, in the Orion spacecraft atop NASA's SLS rocket, and travel to lunar orbit to rendezvous and dock with Starship HLS. Two of the crew members will transfer to Starship HLS, which will transport them to the lunar surface, and land near the south pole. Up to four moonwalks are planned during the 6.5-day stay. Instruments carried to the surface will investigate the seismic and physical properties of the Moon. After liftoff, the Starship HLS will rendezvous with the orbiting Orion, and all four astronauts will return to Earth aboard the Orion.

Although published timelines call for Artemis 3 to land on the Moon by the end of 2026, NASA's internal baseline for the landing has been pushed back to February 2028. Many engineering milestones must be met before the flight is approved. These include resolving unexpected pitting and erosion suffered by the Orion spacecraft's heat shield on Artemis 1 as well as challenges faced by Axiom Space in developing the Artemis lunar spacesuit. A history of previous ambitious spaceflight programs suggests it is prudent to manage expectations and expect Artemis 3 to finally fly in late 2028.

A critical variable in the Artemis scheme is the apparent underperformance of the SpaceX Super Heavy rocket. Instead of 100 tons (90,000 kg) of cargo or fuel being placed in orbit, the currently achievable figure is closer to 50 tons (45,000 kg). Unless rectified, this will necessitate perhaps twice as many tanker spacecraft launches, extending the filling of the fuel depot spacecraft to an unwieldy six-month process. A Starship in-orbit refueling demo is expected in 2025.

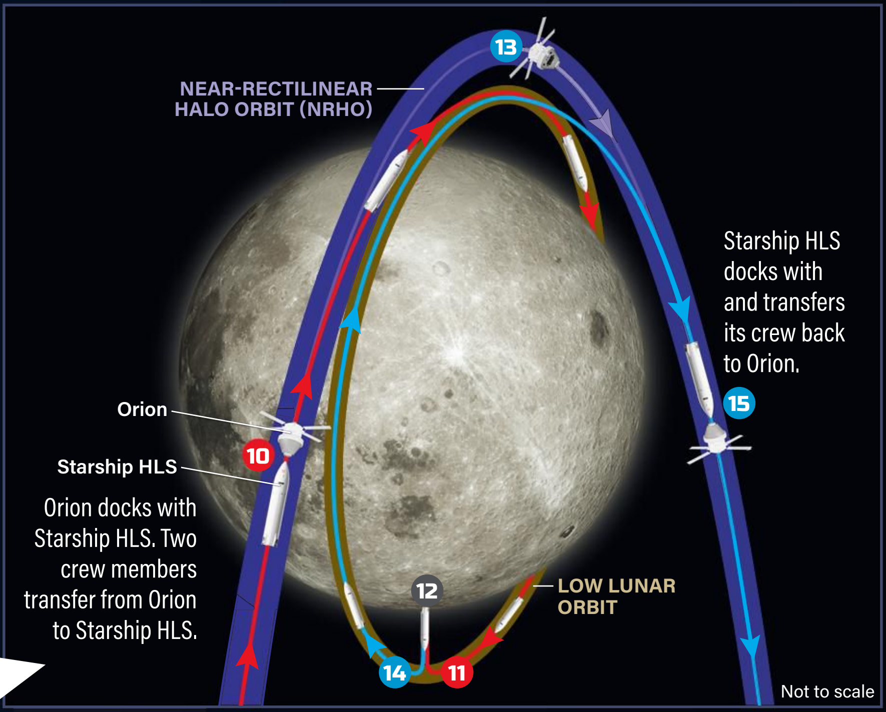
The current performance of the Super Heavy is not fatal to Artemis, but it could delay the program's lunar landings by up to five years. It will likely take longer than that for SpaceX to perfect the higher-performance Raptor 3 engines that will restore the Super Heavy booster to its baseline of placing 100 tons into Earth orbit.

BACKGROUND ILLUSTRATION AND INSETS UNLESS OTHERWISE STATED: *ASTRONOMY*: ROEN KELLY


LOW EARTH ORBIT
Starship HLS lander
Lander
EARTH

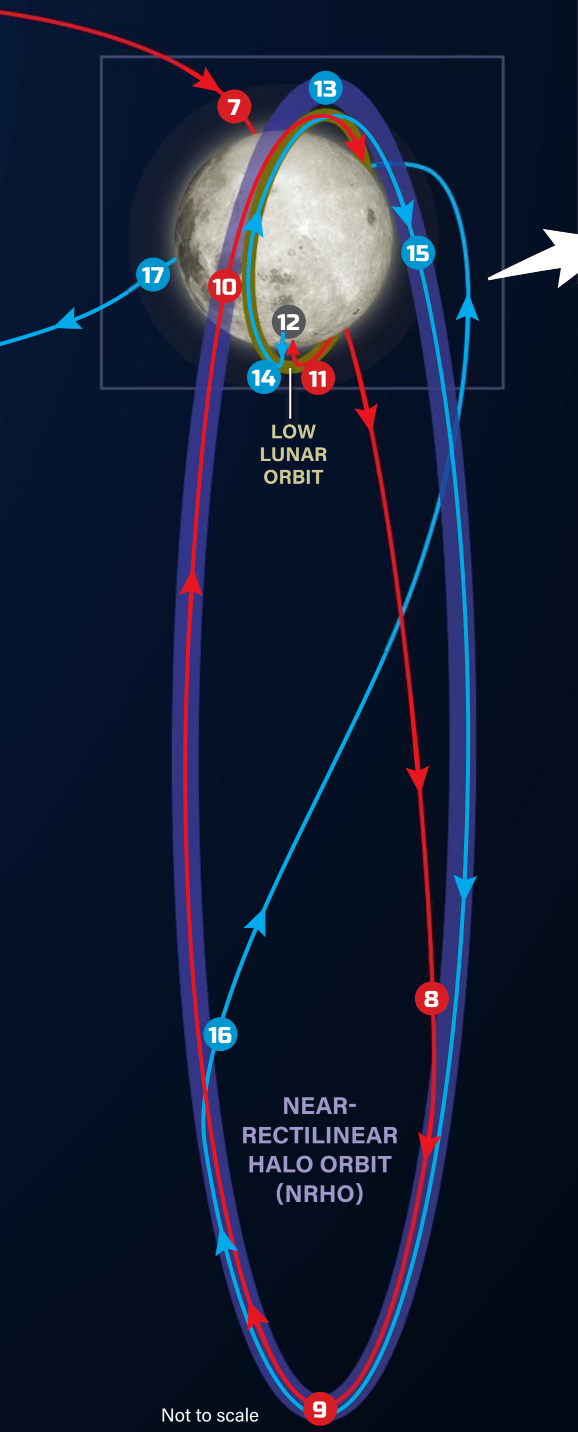
Once the depot is filled, the Starship HLS lander launches and docks with the depot to refuel.

The lander undocks from the depot and travels to the Moon.

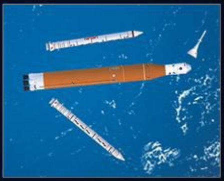

NEAR-RECTILINEAR HALO ORBIT (NRHO)
13
Orion
Starship HLS
10
15
12
LOW LUNAR ORBIT
14
11
Not to scale

Starship HLS docks with and transfers its crew back to Orion.

Orion docks with Starship HLS. Two crew members transfer from Orion to Starship HLS.

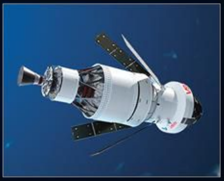

7
13
17
10
15
12
14
11
LOW LUNAR ORBIT
8
16
NEAR-RECTILINEAR HALO ORBIT (NRHO)
9
Not to scale

① SLS launches from Kennedy Space Center, Florida.



② Solid rocket boosters, fairings, and launch abort system jettisoned.

ROEN KELLY AFTER NASA



③ Solid rocket boosters, fairings, and launch abort system jettisoned.

ROEN KELLY AFTER NASA

④ Perigee raise burn to low Earth orbit.

⑤ Trans-lunar injection burn.

⑥ Four-day trip to the Moon.

⑦ Outbound powered lunar flyby 69 miles (111 km) above surface.

⑧ Lunar orbit insertion burn.

⑨ Rendezvous with Starship HLS.

⑩ Lander undocking and separation.

⑪ Lander descends to surface.

⑫ Week-long lunar surface exploration.

⑬ Orion remains in lunar orbit.

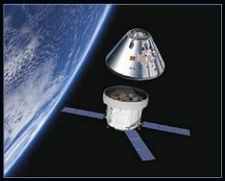
⑭ Starship HLS ascends to low lunar orbit.

⑮ Starship HLS rendezvous and docking with Orion.

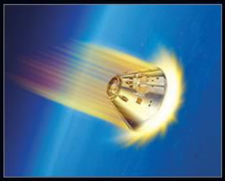
⑯ Orion undocks and performs trans-Earth injection burn.

⑰ Return powered flyby 69 miles (111 km) above surface.

⑱ Final return trajectory correction burn.



⑲ Crew Module separates from Service Module. ROEN KELLY AFTER NASA



⑳ Crew Module reenters atmosphere.

ROEN KELLY AFTER NASA

㉑ Splashdown in the Pacific Ocean. NASA

# NEW ROCKETS FOR THE MOON

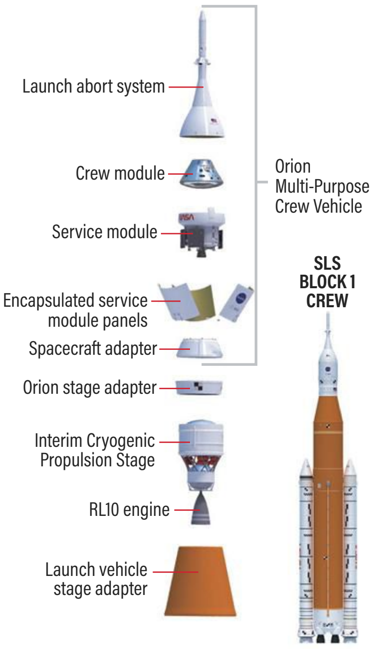
**THE ARTEMIS PROGRAM WILL RELY ON** a fleet of rockets and crewed vehicles. These include NASA's Space Launch System (SLS), the SpaceX Starship/Super Heavy system, and the Blue Origin New Glenn.

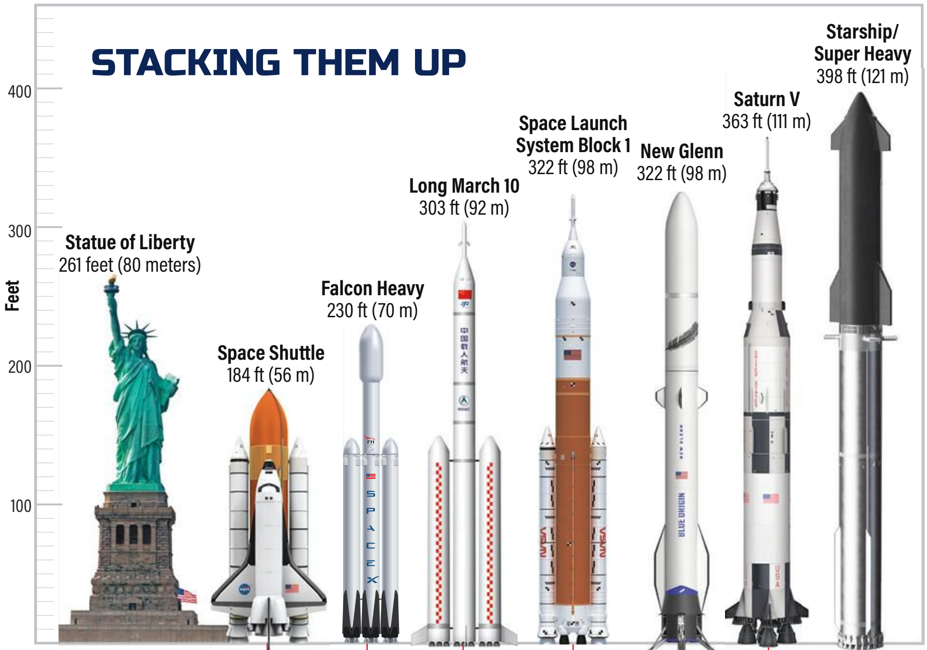
NASA's 322-foot-tall (98 m) SLS will send the crewed Orion spacecraft into lunar orbit to join the awaiting lunar landing craft. The SLS consists of a core booster utilizing four repurposed RS-25 engines from NASA's retired space shuttle, and two nonrecoverable uprated solid rocket boosters (SRB), also adapted from the shuttle.

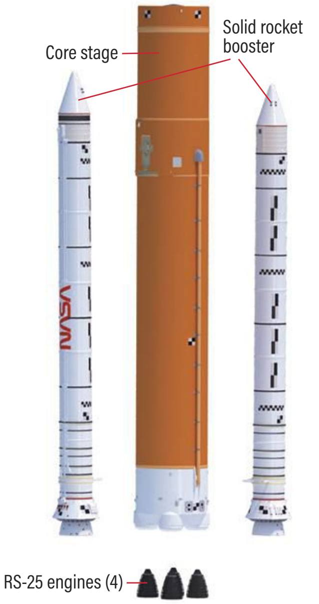
The first four SLS flights will expend the 16 remaining space shuttle RS-25 main engines, and the first eight SLS missions will expend the remaining shuttle SRBs. Subsequent missions will utilize newer uprated engines now under development.

The initial configuration of SLS makes use of an upper stage modified from a Delta rocket built by United Launch Alliance. Called the Interim Cryogenic Propulsion Stage, it will be replaced by an uprated upper stage on Artemis 4. This will allow SLS launches to bring additional Lunar Gateway modules, riding piggyback on the Orion crewed spacecraft.

It is clear that the longevity of the SLS booster will be limited due to its staggering cost — currently estimated as high as $2 billion per launch — and its low flight rate. Currently, there is not enough SLS hardware to support an annual launch rate and the required SLS upgrades for Artemis 4 may delay that mission until late 2028. There are hopes that SLS could launch various future robotic space probes to lower the unit cost to as low as $1 billion per flight, but it is difficult to attract users for such an expensive vehicle. Eventually, more affordable reusable commercial launch capabilities will render the SLS obsolete, and it will vanish from the spaceflight manifest. *—R.R.*


Launch abort system
Crew module
Service module
Encapsulated service module panels
Spacecraft adapter
Orion Multi-Purpose Crew Vehicle
Orion stage adapter
Interim Cryogenic Propulsion Stage
RL10 engine
Launch vehicle stage adapter
SLS BLOCK 1 CREW

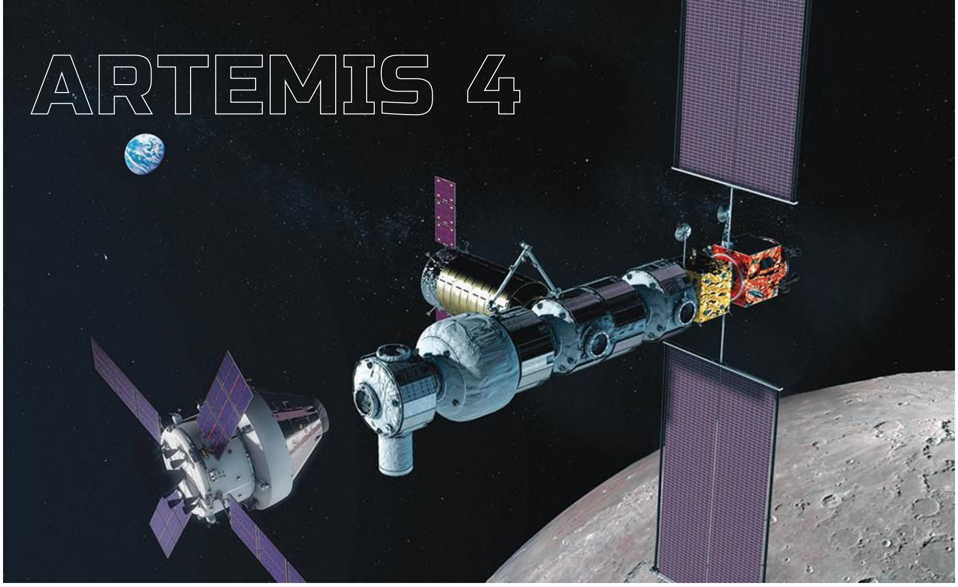




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Manufacturer** | Rockwell et al. | SpaceX | China Academy of Launch Vehicle Technology | Boeing et al. | Blue Origin | Boeing et al. | SpaceX |
| **Weight** | 4,500,000 lbs (2 million kg) | 3,126,000 lbs (1,421,000 kg) | 4,826,000 lbs | 5,750,000 lbs (2.6 million kg) | Undisclosed | 6,200,000 lbs (2.8 million kg) | 11,000,000 lbs (5 million kg) |
| **Liftoff thrust** | 7,800,000 lbs (35 million N) | 5,100,000 lbs (23 million N) | 5,900,000 lbs (26 million N) | 8,800,000 lbs (39 million N) | 3,850,000 lbs (17.2 million N) | 7,600,000 lbs (34 million N) | 16,700,000 lbs (74 million N) |
| **Lunar payload** | N/A | 35,000 lbs (16,000 kg) | 59,500 lbs (27,000 kg) | 59,500 lbs (27,000 kg) | 15,000 lbs (7,000 kg) | 96,000 lbs (43,500 kg) | 150 tons (with low Earth orbit refueling) |
| **Fuel** | $LH_2$/LOX/Solid propellant | RP-1/LOX | RP-1/LOX | $LH_2$/LOX/ Solid propellant | Methane/LOX | RP-1/LOX/$LH_2$ | Methane/LOX |
| **Reusable** | Partially | Yes | No | No | Yes | No | Yes |
| **Cost per launch** | $1,500,000,000 | $90,000,000 | Unknown | $2,000,000,000 | $68,000,000 (estimated) | $1,500,000,000 (adjusted for inflation) | $100,000,000 (estimated) |

FROM LEFT TO RIGHT: STUART MONK/DREAMSTIME; NERTHUZ/DREAMSTIME AND ROEN KELLY; SUBHAN BAGHIROV/DREAMSTIME; ROEN KELLY; NASA; BLUE ORIGIN; NASA; SPACEX; NASA

## ARTEMIS 4



The Lunar Gateway, a small space station in a six-day lunar orbit, will be used as staging point for the Artemis 4 and later lunar landings. In this artist's rendering, an Orion craft approaches for docking. NASA

**STARTING WITH ARTEMIS 4,** a small space station called the Lunar Gateway will circle the Moon in a six-day orbit and serve as a staging point for lunar landings. The initial two Gateway modules will be launched aboard a SpaceX Falcon Heavy rocket. The Artemis 5, 6, and 7 missions will piggyback additional Gateway modules with the Orion spacecraft.

Mission planning for Artemis 4 depends on Artemis 3's timeline. Current public announcements call for launching no earlier than September 2028; a more realistic date is late 2029. Artemis 4 will use the uprated SLS Block 1A rocket, which will have an additional 33,000 pounds (15,000 kg) of payload capacity allowing it to carry the International Habitation Module (I-Hab) being developed by the European and Japanese space agencies. The I-Hab, along with the modules previously launched by the Falcon Heavy, will establish a functional Lunar Gateway outpost. As with the previous mission, the Starship HLS will launch first, rendezvous with the Lunar Gateway, and await the arrival of Orion and the Artemis 4 crew. Two astronauts will then perform the second Artemis lunar landing aboard the Starship HLS. Then all crew members will return to Earth aboard the Orion craft.

## ARTEMIS 5 — and beyond

**TENTATIVELY PLANNED** for launch no earlier than March 2030, Artemis 5 will feature the first use of Blue Origin's Blue Moon lander, which will be launched to the Lunar Gateway by a Blue Origin New Glenn rocket. Four astronauts will launch aboard an Orion spacecraft on an SLS rocket which will also carry an additional module for the Lunar Gateway. At the Gateway, two astronauts will transfer to the Blue Moon for a south pole landing near a prepositioned rover, called the Lunar Terrain Vehicle (LTV). The LTV will be the first use of a lunar rover on the Moon since Apollo 17 in 1972. After returning to the Gateway, the pair will join the other two crew members aboard the Orion for their return to Earth.

If these initial Artemis lunar landings go well, future landings will follow at roughly one-year intervals. Each will utilize the Lunar Gateway to transfer crew from Orion to either a Starship HLS or Blue Moon lander.

There are currently serious technical and financial challenges along Artemis' path to the Moon. The optimistic public schedules will certainly become fiction. But as long as there is a national will to return to the Moon hand-in-hand with international partners, these obstacles can be overcome and more human footprints will join those left on the Moon half a century ago by the heroes of the Apollo era.

**Robert Reeves** *is an accomplished astrophotographer and author, with a passion for lunar photography and science.*

TOP TO BOTTOM: NASA's Space Launch System lifts off from Launch Complex 38B at Kennedy Space Center Nov. 16, 2022, on Artemis 1. NASA/JOEL KOWSKY

The SpaceX Starship/Super Heavy combination is a rocket of astonishing proportions. Fully stacked, the stainless steel rocket stands 30 feet (9 m) wide and 398 feet (121 m) high. With 33 methane-burning Raptor engines, Super Heavy has more than double the thrust of Apollo's Saturn 5. To recover Super Heavy for reuse, SpaceX will catch the booster in mid-air with moving arms on the rocket's launch tower. This process was tested successfully during a test flight Oct. 13, 2024. SPACEX

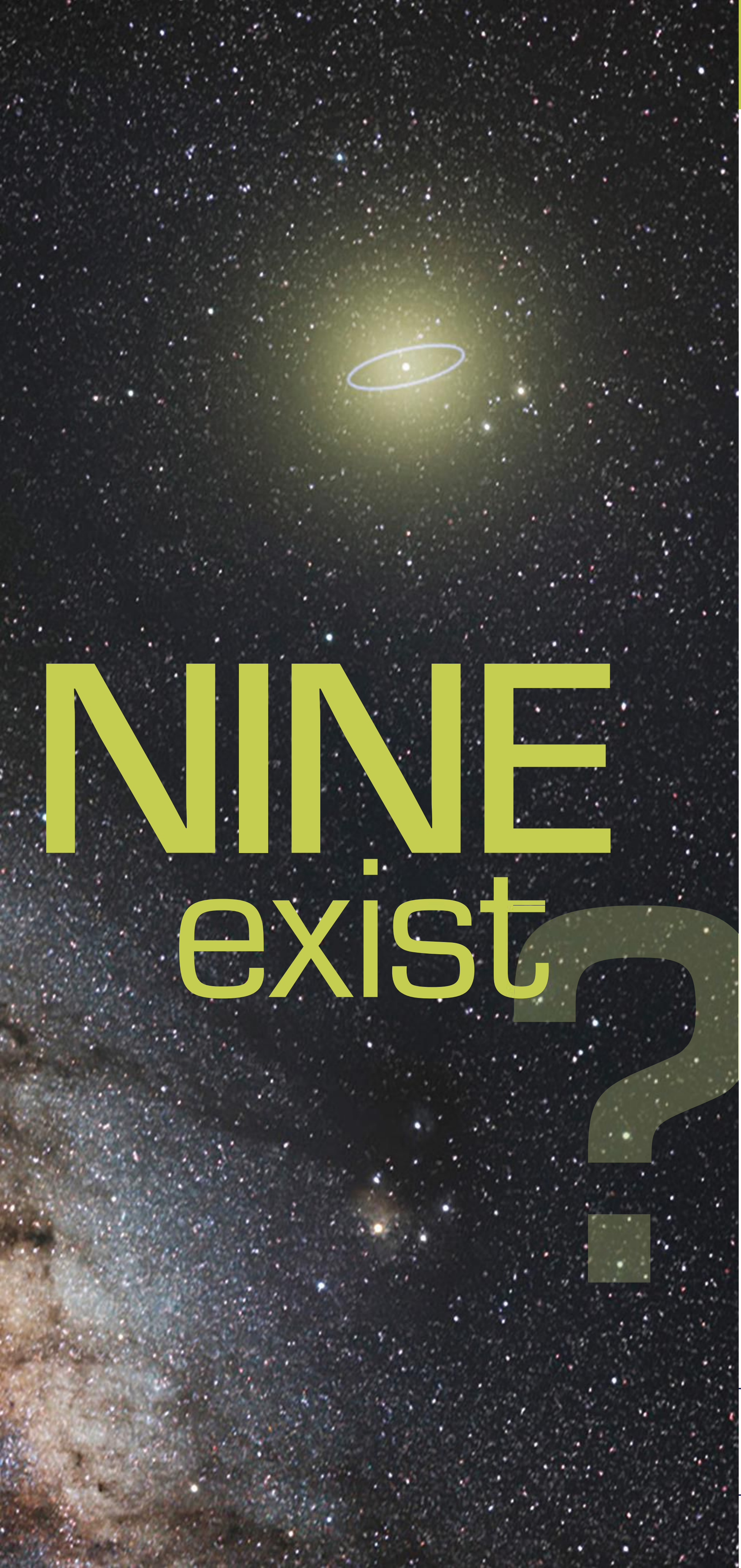
The first components of the reusable Blue Origin New Glenn rocket stand at Cape Canaveral for testing and integration prior to a maiden flight scheduled for late 2024. New Glenn will refuel on-orbit and transport the Blue Origin Blue Moon lunar lander to the Gateway in support of Artemis 5 and later missions. BLUE ORIGIN

# Does PLANET

If this hypothesized super-Earth lurks in the outer solar system, we should see it soon.

BY DAVID L. CHANDLER

# NINE exist?



The hypothetical Planet Nine is imagined as an ice giant in this artist's conception. Neptune's orbit is shown as the ellipse around the distant Sun (upper right). ESO/TOM RUEN/NAGUALDESIGN

**GROWING UP,** I was taught that there were nine planets in the solar system. That all changed in 2006, when the International Astronomical Union voted to demote Pluto's status to that of dwarf planet. But now, there is a chance that within the next year or two, the solar system could once again be graced with nine official, full-fledged planets.

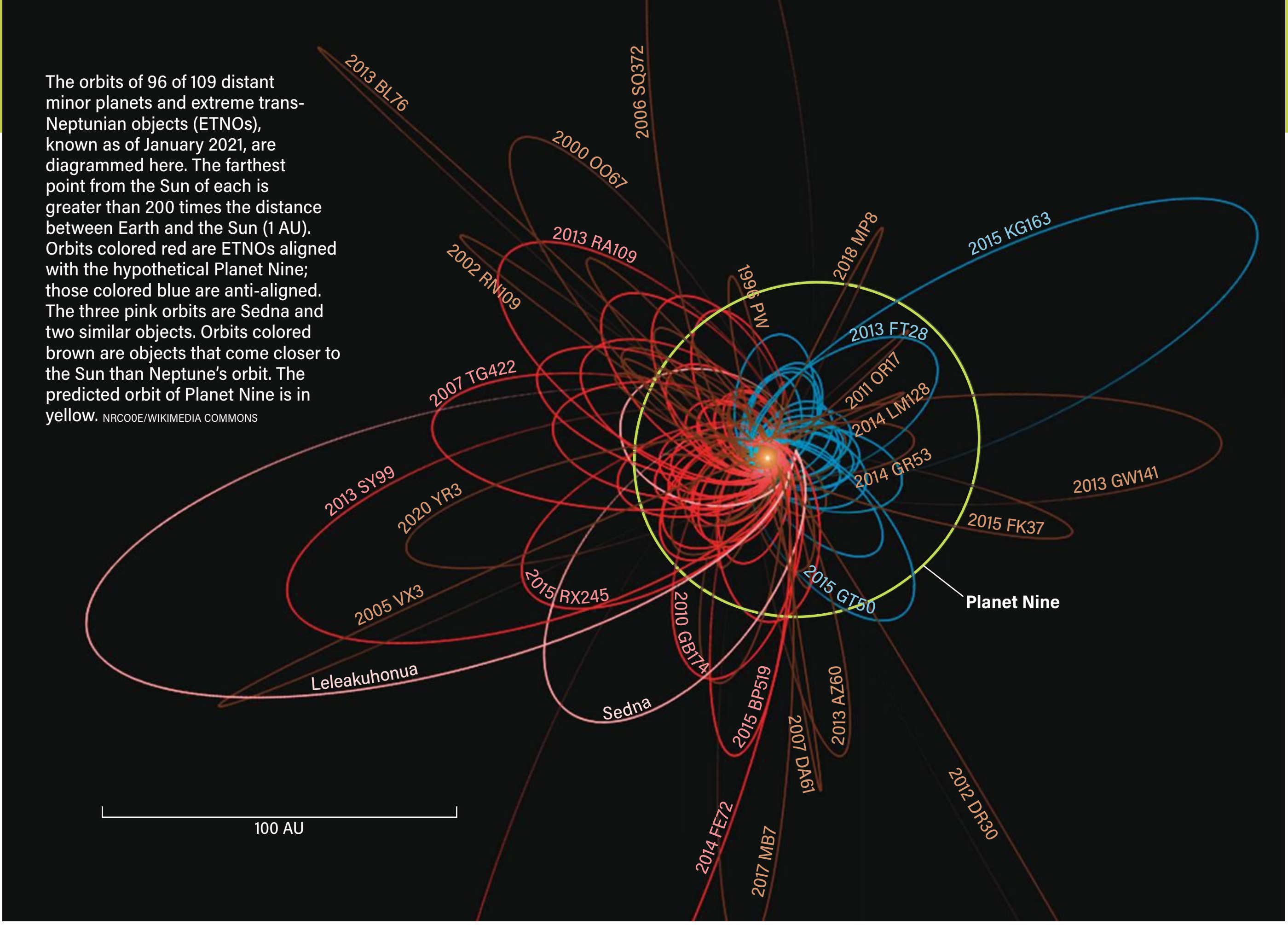
The newcomer replacing Pluto presently goes by "Planet Nine." If and when it finally shows up, it will get the honor of a real name, but so far, the evidence for this hypothetical planet is all indirect. Just as many of the thousands of known planets orbiting other stars have been found by observing their gravitational effects, rather than by actually seeing them, Planet Nine has been identified thanks to the way it has apparently been tugging on a variety of small bodies in the outer solar system and pulling their orbits into lockstep patterns. If it exists, Planet Nine orbits the Sun at an average distance around 550 astronomical units (AU), or 550 times as far as Earth is from the Sun. Astronomers also think it has between five and 10 times Earth's mass.

Some astronomers think that the body of evidence is already overwhelming. Others are not convinced. But this nearly decade-long debate is reaching a critical point: A new observatory is coming online that should give astronomers the chance to find it. If Planet Nine does exist, the chance to see it may be just around the corner.

## Weird orbits

The story of Planet Nine begins with oddities in the orbits of objects in the solar system.

In 2016, Caltech astronomers Michael Brown and Konstantin Batygin reported six small bodies in the outer solar system that had strange, anomalous orbits. These six objects, which orbit far out beyond Neptune, are members of the



The orbits of 96 of 109 distant minor planets and extreme trans-Neptunian objects (ETNOs), known as of January 2021, are diagrammed here. The farthest point from the Sun of each is greater than 200 times the distance between Earth and the Sun (1 AU). Orbits colored red are ETNOs aligned with the hypothetical Planet Nine; those colored blue are anti-aligned. The three pink orbits are Sedna and two similar objects. Orbits colored brown are objects that come closer to the Sun than Neptune's orbit. The predicted orbit of Planet Nine is in yellow. NRCO0E/WIKIMEDIA COMMONS

category of so-called extreme trans-Neptunian objects (ETNOs) who orbit on average 150 times farther from the Sun than Earth. Among the half-dozen is the first known ETNO, the dwarf planet Sedna.

The six curiosities that Brown and Batygin identified have elongated elliptical orbits whose perihelia (their closest points to the Sun) seem to be aligned, although researchers would expect them to be randomly distributed. What's more, their orbital planes are all tilted by about 18° from the plane of the solar system's planets, and yet their perihelia all fall almost precisely on that plane. "That grouping, that confinement, requires some kind of gravitational tug," Batygin says.

The paths of these ETNOs, the pair argued, could best be explained by the influence of a large planet orbiting in a highly elliptical orbit far out beyond Neptune. In the years since that original proposal, additional ETNOs have been found that exhibit this same orbital clustering, bringing the number to 14. Without the influence of another large planet, he says, "if you let them go, they would precess out of alignment," ending up in the expected random distribution.

> "The giant planets play soccer with these smaller objects."
>
> —Konstantin Batygin

The third line of evidence came from a separate population of unusual asteroids. Their orbits are nearly perpendicular to the plane of the solar system. "No one had been able to explain" these odd orbits, Brown says, "and they are, again, a very natural consequence of Planet Nine." Additionally, there is a population of more than a dozen asteroids within the group known as Centaurs (asteroids that orbit between Jupiter and Neptune) with highly inclined orbits, orbiting the Sun in the opposite direction from the planets and most other asteroids.

"This is another population of bodies that comes out naturally from the Planet Nine hypothesis," Batygin says. Taken together, these anomalies can't be "explained with the conventional understanding of how the solar system formed and how it evolved," Batygin says.

## Clustering questions

The initial hypothesis was greeted with skepticism. At least two other groups who have discovered additional ETNOs have concluded that the apparent clustering does not rise to the level of a statistical anomaly. Instead, it may simply be a result of our limited ability to find them. Because ETNOs are on such extreme orbits, they can only be detected when they happen to be near their perihelia (their closest point to the Sun); otherwise, they are too distant and faint. And the ground-based telescopes that conduct searches for such objects are limited in where they can look on the sky. Samantha Lawler, an astronomer at the University of Regina, Saskatchewan, was co-author of one of these studies, based on a project called the Outer Solar System Origins Survey.

"Our data for these most extreme objects is completely consistent with a random distribution," she says, and therefore does not require any special explanation such as an extra planet. "I really don't think there is any clustering," she adds. Another study using data from the Dark Energy Survey, "which was completely independent of us, also found the same thing." Lawler says. "So that's two surveys where we kept very careful track of the biases, and we both don't see the evidence there."

But she and her colleagues are still looking, she notes. They are part of an ongoing survey using the Canada-France-Hawaii Telescope on Maunakea, Hawaii, "where we are specifically trying to find the most distant extreme Kuiper Belt objects that we can, in uniform directions around the solar system. So the idea is we will test the clustering."

Because both of the studies that failed to confirm the clustering involved small numbers of objects — each only found four ETNOs — her team's study has been criticized for insufficient data. "The critique we have gotten from [Brown and Batygin's] group is that we didn't find enough extreme Kuiper Belt objects," Lawler says. Of the four they found, two were consistent with the suggested clustering, one was perpendicular to the line of that cluster, and the other was 180° away. "So, of the four we discovered, two were completely outside the clustering. So statistically that is consistent with a uniform distribution," she says.

## New lines of evidence

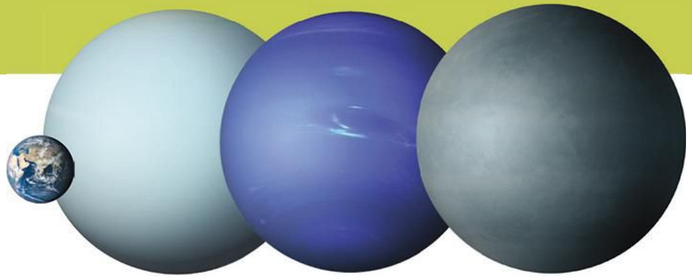
Just last year, Brown and Batygin, along with three co-authors, published research in *The Astrophysical Journal Letters* citing new lines of evidence in support of the Planet Nine hypothesis. They hope that the question will be answered once and for all within the next year or so.

The new work found that it's not only objects in the far outer solar system that are perturbed by the gravity of this distant giant planet. According to hundreds of thousands of simulations of asteroid orbits and their evolution, they found that there should be a clearly discernible effect on asteroids orbiting inside Neptune's orbit as well.

It's all part, says Batygin, of the way "the giant planets play soccer with these smaller objects." In this game, Neptune is the goalie. Every once in a while, objects from the Kuiper Belt get perturbed by some random encounter and sent inward, but the influence of Neptune's gravity — the first giant planet they would encounter on their inward journey — tends to trap them and prevent further progression. Eventually, by lingering too close to Neptune's orbit, these objects will get ejected from the solar system. This should create a sharp drop in the population of the objects with elongated orbits as you get closer to the Sun than Neptune, because Neptune gets in the way.

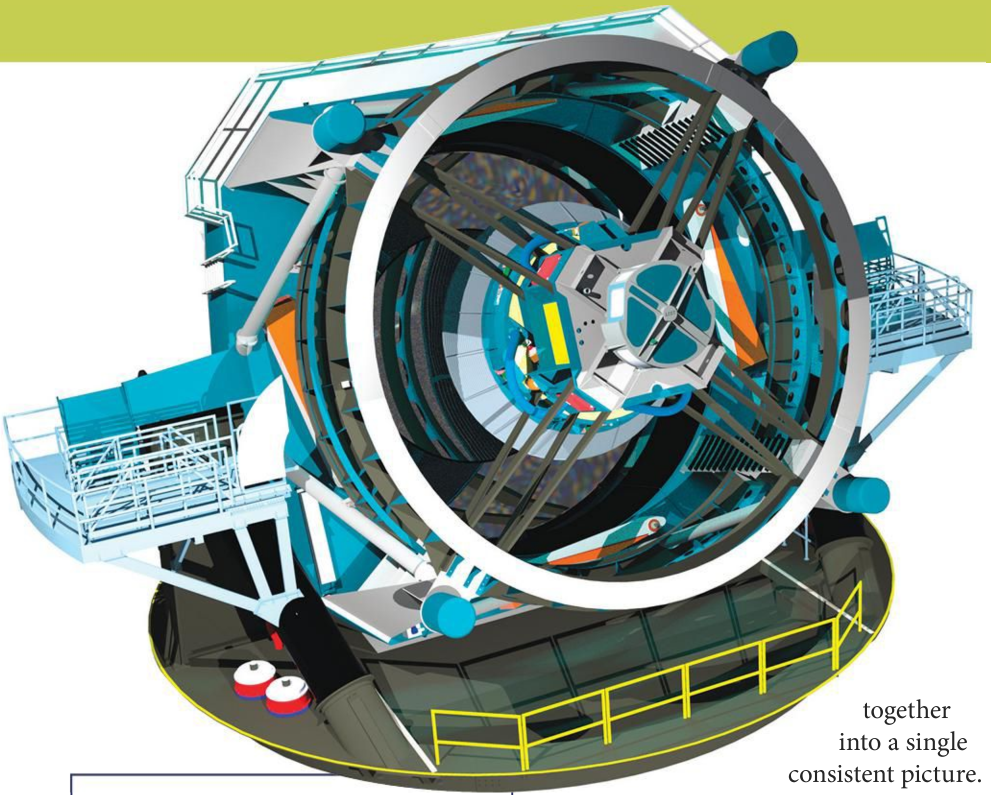
But if Planet Nine is farther out and constantly taking shots on goal, perturbing more Kuiper Belt objects and sending them inward all the time, then Neptune just can't keep up, and some will get through. "As a consequence," Brown says, "if Planet Nine exists, there should

### SIZING UP PLANET NINE



| | Earth | Uranus | Neptune | Planet Nine |
|---|---|---|---|---|
| MASS | 1 | 14.5 | 17 | 10 |
| RADIUS | 1 | 4 | 3.9 | 3.7 |
| LENGTH OF YEAR | 1 | 84 | 164.8 | 10,000 to 20,000 |
| AVERAGE TEMPERATURE | 59° F (15° C) | –357° F (–216° C) | –360.4° F (–218° C) | –374.8° F (–226° C) |

Currently, a team of researchers is using the Canada-France-Hawaii Telescope to find the most distant Kuiper Belt objects. This project, called the Outer Solar System Origins Survey, may provide data to prove or disprove the existence of Planet Nine. VADIM KURLAND/FABIAN_RRRR/WIKIMEDIA COMMONS



The soon-to-be-operational Simonyi Survey Telescope is housed within the Vera C. Rubin Observatory in Chile. This instrument, shown here in a rendering, contains an 8.4-meter primary mirror and will image the entire southern sky every three nights.
LSST PROJECT OFFICE

be a pretty smooth population of objects that have a perihelion distance from just outside Neptune's orbit to all the way in to Uranus and even further."

And that's just what they found when they analyzed the orbits of about a dozen ETNOs. "With a pretty nice analysis that's hard to argue with, we showed that it is definitely a smooth population that goes in all the way to Uranus and beyond, and doesn't stop at Neptune," Brown says.

Batygin says that "a Planet Nine-free solar system is incompatible with this data at the five-sigma level," meaning the odds are 3.5 million to 1 against it. On the other hand, he says, "a solar system simulation that includes Planet Nine is indistinguishable from the real data."

## Something out there?

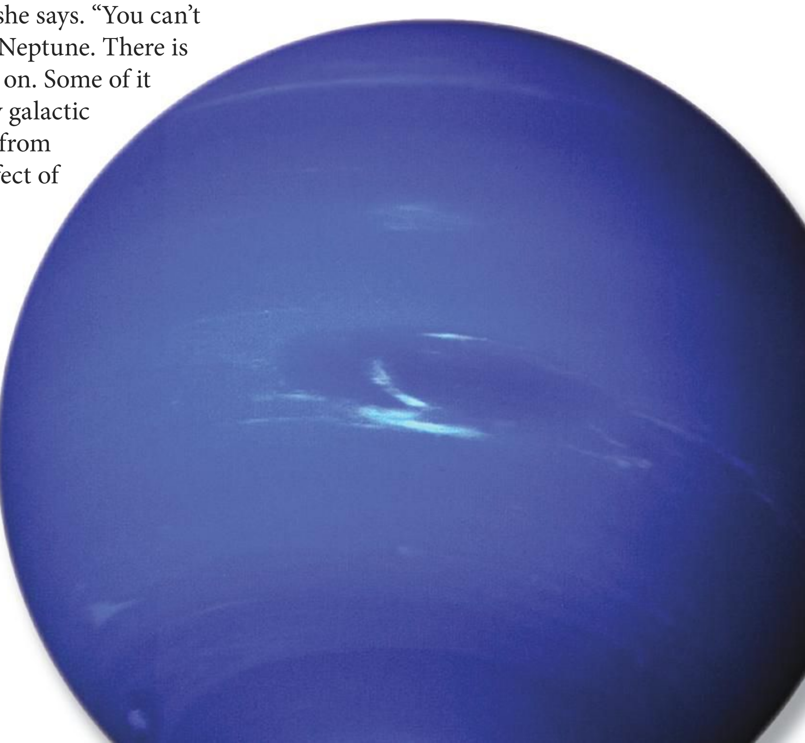
Brown concedes that none of the lines of evidence alone provides proof of Planet Nine's existence. But all of these different anomalies require explanation, and the Planet Nine concept ties them all together into a single consistent picture. Without Planet Nine, each would require individual explanation, which nobody has yet proposed in a consistent way, he says. And although some astronomers are skeptical of the apparent clustering that formed the basis for the initial Planet Nine hypothesis, Lawler — who is one of those skeptics — concedes that some of the features of those distant orbits, including some of these newer findings, cannot be easily accounted for.

"I think there's a lot of the orbital distribution in the Kuiper Belt that we can't explain currently," she says. "You can't explain it with just Neptune. There is other physics going on. Some of it can be explained by galactic tides," which come from the gravitational effect of the solar system's oscillating motion above and below the plane of the Milky Way as our Sun orbits the center of the galaxy. "But some of it — there has to be something out there that we haven't discovered yet," she says.

What else could it be? Some researchers have suggested the gravitational effects of a star passing nearby long ago. Others imagine an uneven distribution of objects in the Kuiper Belt left over from the massive disk of debris that formed the solar system. Still others think that perhaps a much closer and less massive ninth planet exists, about the size of Mars instead of five to 10 times Earth's mass.

"There's a whole bunch of different theories," she says. It's true that the Planet Nine hypothesis can tie together several different kinds of anomalous findings into one single, simple explanation, she agrees. "That's lovely; that would be great. But the original line of evidence for Planet Nine is this clustering, which I don't think there is evidence for. … I don't think Planet Nine in that exact configuration is something that we're going to find," Lawler says.

Brown says that although the results of their latest research are not as obvious as the similarity of orbits that triggered the proposal of a planet in the first place, they do support the initially hypothesized Planet Nine parameters. "Although the results of this paper aren't as dramatic as the big clustering of objects in the outer solar system, they're pretty irrefutable," he insists. "There's kind of no way to have the results that we did without there being some sort of giant planet out there."



## Putting it to the test

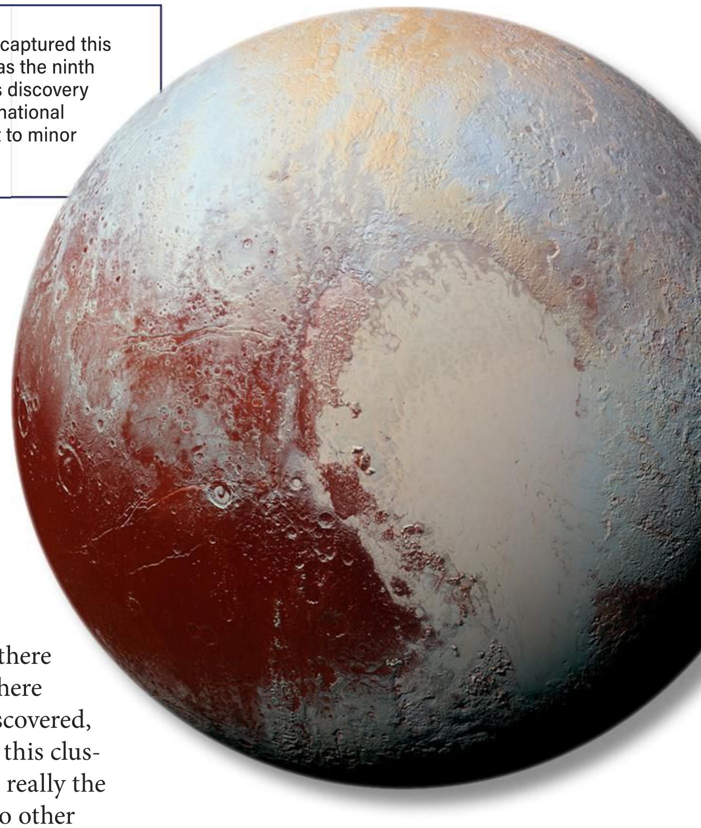
The analysis of the anomalous orbits enabled Brown and Batygin to calculate the likely orbit of Planet Nine. Since then, they have been searching the part of the sky where it is most likely to be.

In a second, more recent paper last year they, along with co-author Matthew Holman from the Harvard-Smithsonian Center for Astrophysics, conducted an exhaustive search using the database of the Pan-STARRS survey. Combined with results of previous searches, they say they have now ruled out 78 percent of the possible locations the giant planet could be. "We can give pretty good guesses," Batygin says, "but we can't predict where it is in its orbit." That's different from the way French astronomer Urbain Le Verrier was able to predict Neptune's precise position in 1846, leading almost immediately to its discovery.

But there's hope on the horizon. The Vera C. Rubin Observatory, nearing completion on a mountaintop in Chile, is expected to come online later this year. When it does, it will image the entire southern sky every three nights, using the largest digital camera ever built.

Planet Nine should be detectable by that telescope. But it would require an adjustment in the planned observing protocol to extend the telescope's survey farther north than planned, Brown says, and that has not yet been decided. If the observatory does make the alteration, he says it should detect Planet Nine — unless the world lies at the extreme edge of its predicted distance or at the low end of its possible brightness.

"There are some reasons to think it could be farther away than our initial predictions," Brown says, "and in that case, Vera Rubin will not be able to track it down either, and I'll be depressed." But if it lies almost anywhere along the predicted path and isn't extraordinarily dark, it should pop into view, likely within Rubin's first year of operation, Brown says.



NASA's New Horizons spacecraft captured this view of Pluto on July 14, 2015. It was the ninth planet of the solar system from its discovery in 1930 until 2006, when the International Astronomical Union reclassified it to minor planet status. NASA/JHUAPL/SWRI

The gravity of the most distant solar system planet currently known, Neptune, tends to eject most small bodies that move inward from the Kuiper Belt, keeping them from getting closer to the Sun. But if Planet Nine exists, gravitational interactions with it would send many more bodies inward than Neptune could eject. Astronomers have discovered a number of those bodies, giving credence to the Planet Nine hypothesis. NASA/JPL-CALTECH

Even if the planet itself is not directly seen, Rubin could provide new evidence. "A nice thing about Rubin is that whether you find Planet Nine or not, it will put to rest any questions about whether there is clustering," Brown says. "There will be many more objects discovered, and it'll be quite obvious that this clustering is real." Planet Nine "is really the only explanation. There are no other explanations for the other strange phenomena out there," he says.

And if Rubin does find the planet, proving its existence and providing an image of it, albeit as just a point of light, what then?

"What I'm looking forward to is not just the discovery, but what we get to do once we discover it," Brown says. "We'll study it with every telescope on the planet and off the planet, and learn if it has moons, if it has rings, what kind of atmosphere or surface does it have, what the full orbit really is. And that'll start to tell us things about how it got there."

Astronomers have been puzzled by the finding that other star systems commonly contain planets with masses between that of Earth and Neptune, called super-Earths. And yet our solar system has no such planet, making the properties of this whole class of abundant planets relatively unknown to us. Finding Planet Nine, which fits smack dab into that range, would change all that. "It's our chance, in a sense, to study what many of these planets that are around other stars might be like, a little bit up close and in person," Brown says.

And the scientific community will want a closer look. "There will be quite a big incentive to actually go there. It'll take a while, it's way out there," some 400 to 800 AU away, he says. (One AU equals the average Earth-Sun distance of 93 million miles [150 million km].) "But as soon as we nail down its position, I think the excitement to go send at least a quick probe out there to take some close-up pictures is going to be too hard to resist."

If Planet Nine is finally discovered, as one of those who first postulated its existence, does Brown have any suggestions for a possible formal name for this new member of the solar system?

"No," he declares. "As an observational astronomer who has to stay up all night and worry about clouds, I'm a very superstitious person. I think most astronomers are. And one of my strongly held superstitions is that if you do propose a name, you'll never find it. So we are just waiting and seeing."

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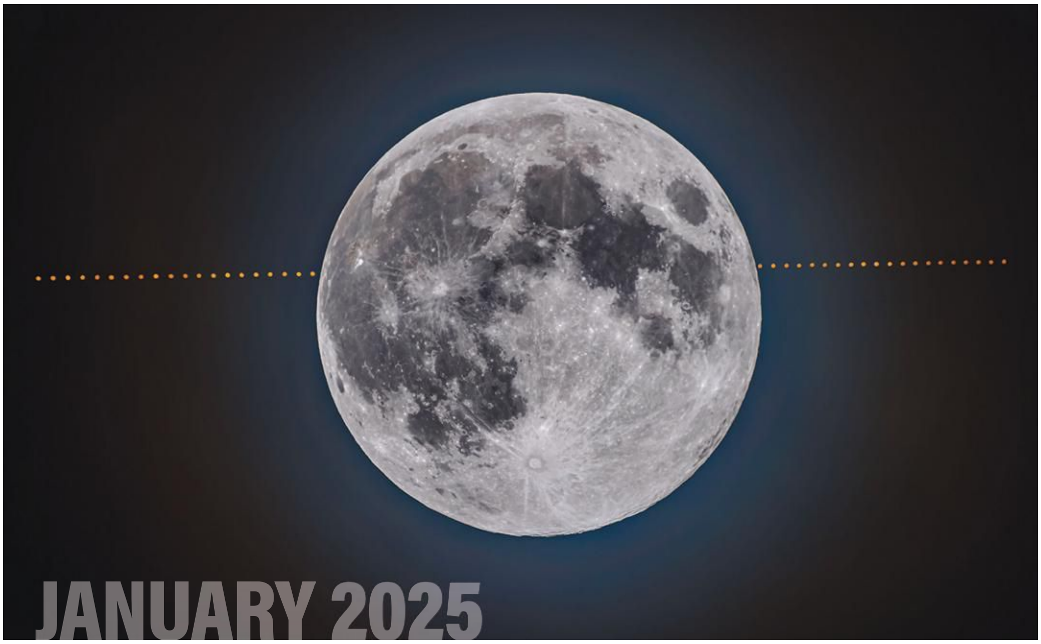
**David L. Chandler** *is a longtime science writer and author who writes frequently about astronomy and space subjects.*

# SKY THIS MONTH

👁 Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

**BY MARTIN RATCLIFFE AND ALISTER LING**



A composite shows the Dec. 7, 2022, occultation of Mars by the Moon. Although the time-lapse image makes it look as though Mars is moving, in reality it was the Moon whose faster relative motion made it appear to pass in front of a stationary Mars in the background. ALAN DYER

# Spotlight on Mars

All the major planets are on view this month. Venus has a fine evening conjunction with Saturn and Jupiter is high in Taurus. Uranus and Neptune are binocular targets, while Mars reaches opposition. Early morning reveals Mercury. Additionally, on the 9th the Moon crosses the Pleiades (M45), and on the 13th it hides Mars in a rare event.

**Venus** dazzles in the southwestern sky after sunset all month. Starting at magnitude –4.4 and brightening quickly, it's easily visible as twilight descends. On the 1st, Venus shows a 55-percent-lit disk spanning 22". On Jan. 2 and 3, the waxing crescent Moon joins in, standing 10° southwest and 4° east of the planet, respectively. Notice on the 4th that the Moon is 4° northeast of Saturn, which is about 13° from Venus.

Venus reaches greatest eastern elongation Jan. 9, 47° from the Sun and setting almost four hours after sunset.

The moment Venus shows a 50-percent-lit disk is called dichotomy. The exact moment can vary from predictions by up to four days. Check on Jan. 11, the predicted date of dichotomy. What do you observe?

Venus closes the gap to Saturn over the next few days, standing just under 4° west of the gas giant on the 14th and coming closest on the 17th, when only 2.2° separates them. By the 19th, Venus is 2.5° due north of the ringed planet, which shines at magnitude 1.1.

Venus crosses into western Pisces on the 23rd and ends the month 1.5° from Lambda (λ) Piscium. Its disk is now 32" across and 38 percent lit.

The best telescopic views of **Saturn** are almost gone, but you have a short period after evening darkness falls. Saturn is 30° high two hours after sunset on the 1st; it sets around 10 P.M. local time on the 1st and 8 P.M. on the 31st. It shines at magnitude 1.1 most of the month and lies south of Phi (ϕ) Aquarii.

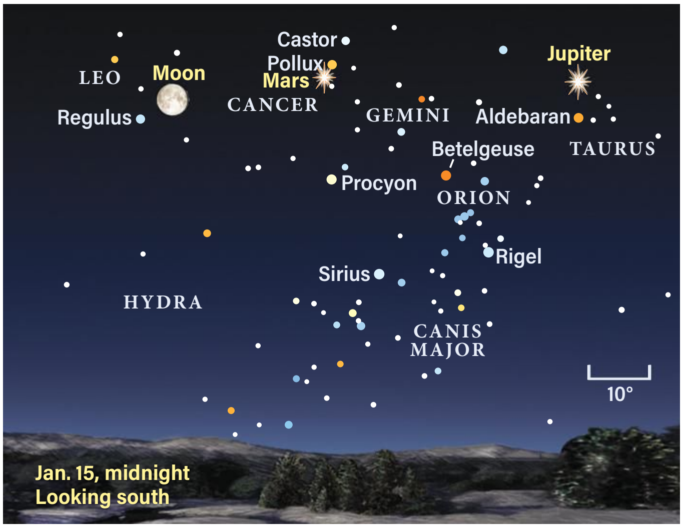
Through a telescope, Saturn's disk spans 16". The rings are widest for the year in the first week of the month at 4°, and narrow to 3° by the 31st. They're edge-on in March.

Titan, Saturn's largest moon, is an easy target for any scope. It stands near the planet Jan. 6, 7, 14, 15, 22, 23, 30, and 31.

Iapetus is at its brightest western elongation, 8' west of Saturn, on New Year's Eve. During the first three weeks of January, it moves toward superior conjunction and fades from 10th to 11th magnitude. On Jan. 20, it lies only 47" due south of Saturn, a great time to spot this enigmatic moon.

**Neptune** sits about 12° east of Saturn. Shining at magnitude 7.8, it can be spotted in binoculars. At

## Mighty Mars



Mars reaches opposition Jan. 15, standing high in the south at midnight. Just days before, the Moon occults the Red Planet. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

## OBSERVING HIGHLIGHT

**MARS** is occulted by **THE MOON** Jan. 13, two days before the planet reaches opposition.

the end of January it lies in the same binocular field as Venus, which acts as a marker to find the distant planet.

Early in January, Neptune forms a nice triangle with 20 and 24 Psc, which shine at magnitude 5.5 and 5.9, respectively. As January progresses, Neptune moves eastward, standing 1° due north of 24 Psc on the 29th. Venus is 3.5° from Neptune and remains a similar distance through the 31st.

**Uranus** appears fixed against the background stars of Aries as it ends its retrograde loop at the end of January. At magnitude 5.7, it's an easy binocular target. Located about 8° southwest of the Pleiades, Uranus is south of a collection of 5th-magnitude stars, the brightest of which is 63 Arietis. Uranus stands 2.5° due south of this star.

It's a great time to find Uranus in a telescope, higher than 60° after 8 P.M. local time. Its 4"-wide disk is a challenge, but try under good conditions with high magnification. It is visible until well after midnight all month.

Dominating Taurus is **Jupiter**, altering the well-known constellation's appearance. Jupiter spends most of January at magnitude –2.7. As soon as darkness falls, it is nearly 40° high in the east, a great time to observe with a telescope. It reaches its highest elevation just before 10 P.M. local time in early January, and two hours earlier at the end of the month.

The planet is 5.5° from a waxing gibbous Moon Jan. 10, and stands 5° north and slightly east of Aldebaran Jan. 31. Jupiter's disk spans 47" on Jan. 1 but drops to 43" by month's end. It offers a wealth of detail even in small scopes. Most days all four Galilean moons — Io,

*— Continued on page 34*

## RISING MOON | Roll with it

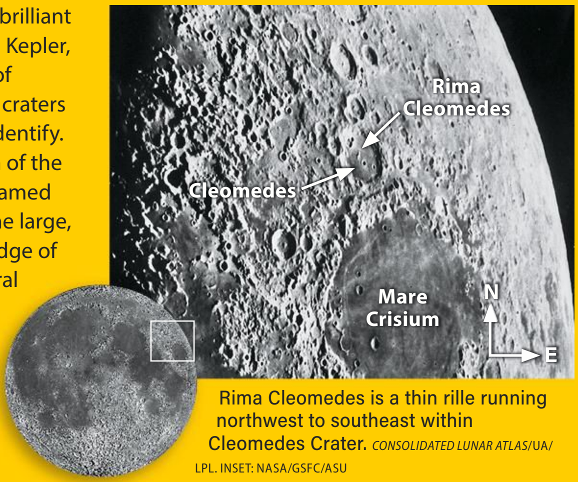
**A NEW YEAR** brings a new crescent. When the earthshine is prominent on the 2nd, pick out "Full Moon" features such as Tycho's rays, brilliant Aristarchus, the aprons of Copernicus and Kepler, and of course the lunar seas. The jumble of bright and dark arcs of the foreshortened craters on the lit crescent can be a challenge to identify.

By the 3rd, the oval Sea of Crises north of the equator is fully illuminated. Cleomedes, named after a 1st-century Greek astronomer, is the large, 80-mile-wide crater adorning the north edge of Mare Crisium. An off-center hint of a central peak pokes out of the lava-covered floor, which is pocked by a couple of decent craters about 7 miles across. Kick up the magnification to seek out the long but thin rille, named Rima Cleomedes. Be patient for moments of clarity when the atmosphere above us steadies. These smaller features will disappear under a higher Sun on subsequent evenings.

Visible to the unaided eye over the next two weeks, Crisium seems to roll northward while the highlands climb away from the southern limb. Relative to Earth's orbit on the ecliptic, Luna arcs above it enough for us to see "under her chin" — astronomers call this optical libration. From the 11th to the 15th, look for tall mountains and shadows at the lunar south pole.

You might be almost as captivated watching the sunset shadows swallow up the terrain in the evenings after Full phase on the 13th. The reversed lighting practically turns this into undiscovered country. Do it all again when the thin crescent returns on the 30th.

**Cleomedes**



Rima Cleomedes is a thin rille running northwest to southeast within Cleomedes Crater. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

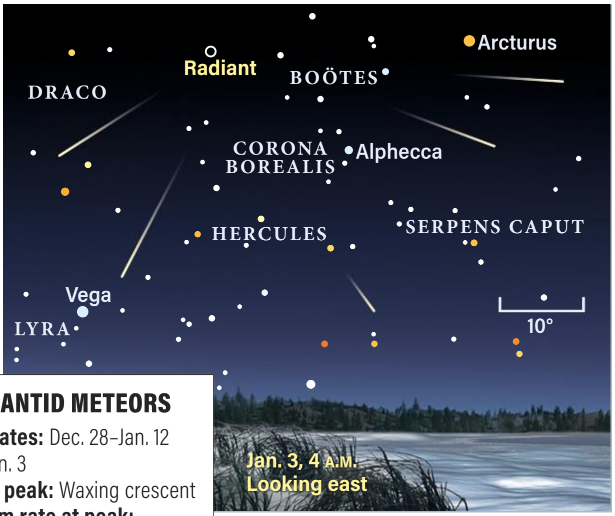
## METEOR WATCH | Starting the year off right

**WITH A WAXING CRESCENT** Moon in the early-evening sky, the conditions are set for the annual Quadrantid meteor shower. It peaks Jan. 3 and is best viewed in the hours before dawn.

The Quadrantids are active between Dec. 28 and Jan. 12, with a narrow peak. The radiant rises soon after 9 P.M. local time, and by 4 A.M. it's about 45° high. Expect about 25 to 30 meteors per hour if the peak occurs during the dark window of your observing site, corresponding to a maximum zenithal hourly rate of nearly 100, making it one of the best showers of the year.

The Quadrantids' parent object, 2003 EH$_1$, was discovered in 2003 by Brian Skiff at Lowell Observatory.

**Quadrantid meteor shower**



The Quadrantids are named for a defunct constellation that lies in northern Boötes.

### QUADRANTID METEORS

**Active dates:** Dec. 28–Jan. 12
**Peak:** Jan. 3
**Moon at peak:** Waxing crescent
**Maximum rate at peak:**
80 meteors/hour

# STAR DOME

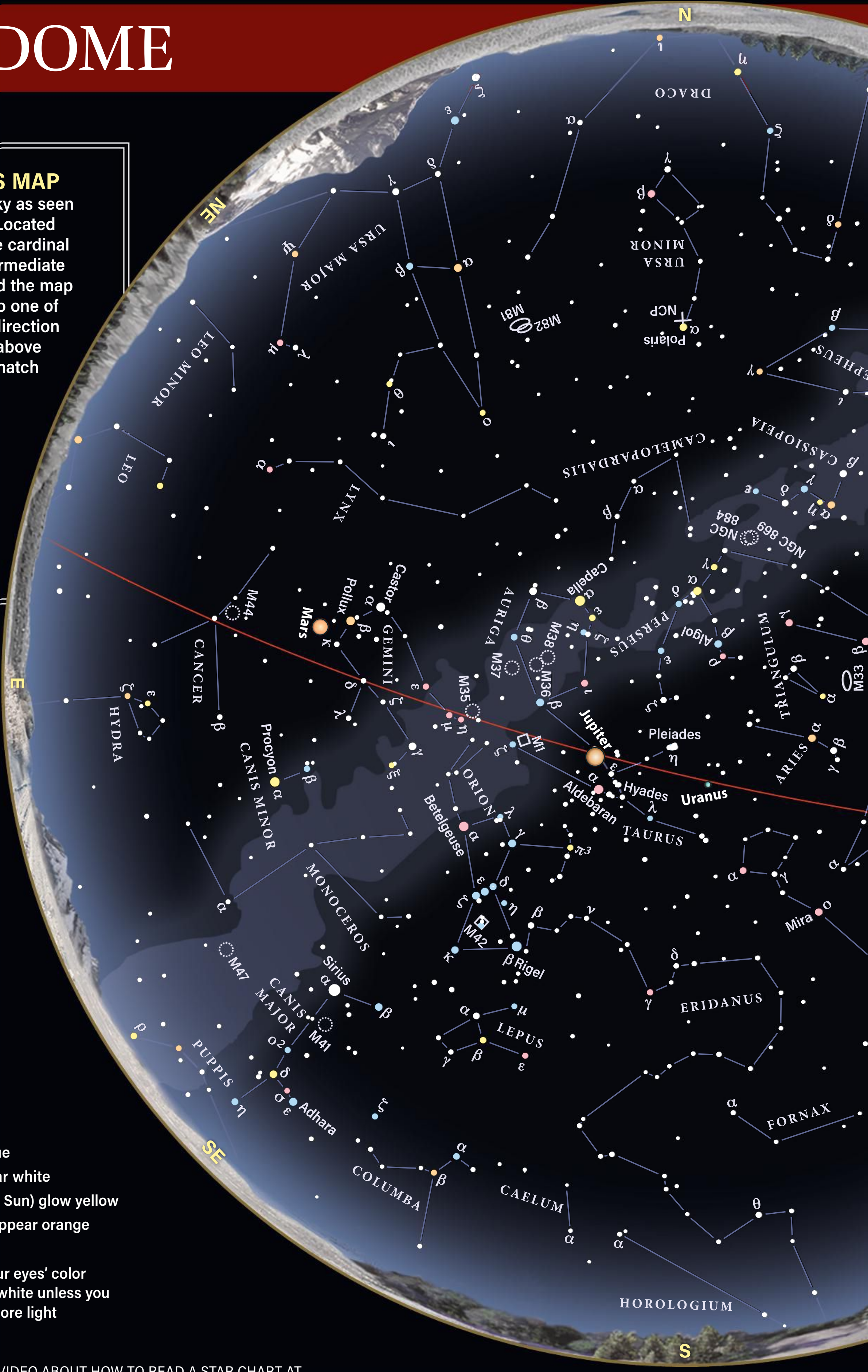
## HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 31

Planets are shown at midmonth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Capella
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PERSEUS
Algol
TRIANGULUM
M33
M44
CANCER
Mars
Pollux
Castor
GEMINI
M35
M37
M36
M38
HYDRA
Procyon
CANIS MINOR
M1
Jupiter
Pleiades
Hyades
Aldebaran
Uranus
TAURUS
ARIES
ORION
Betelgeuse
MONOCEROS
M42
Rigel
Mira
M47
Sirius
CANIS MAJOR
M41
ERIDANUS
LEPUS
PUPPIS
Adhara
COLUMBA
CAELUM
FORNAX
HOROLOGIUM

## MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- □ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

## STAR MAGNITUDES

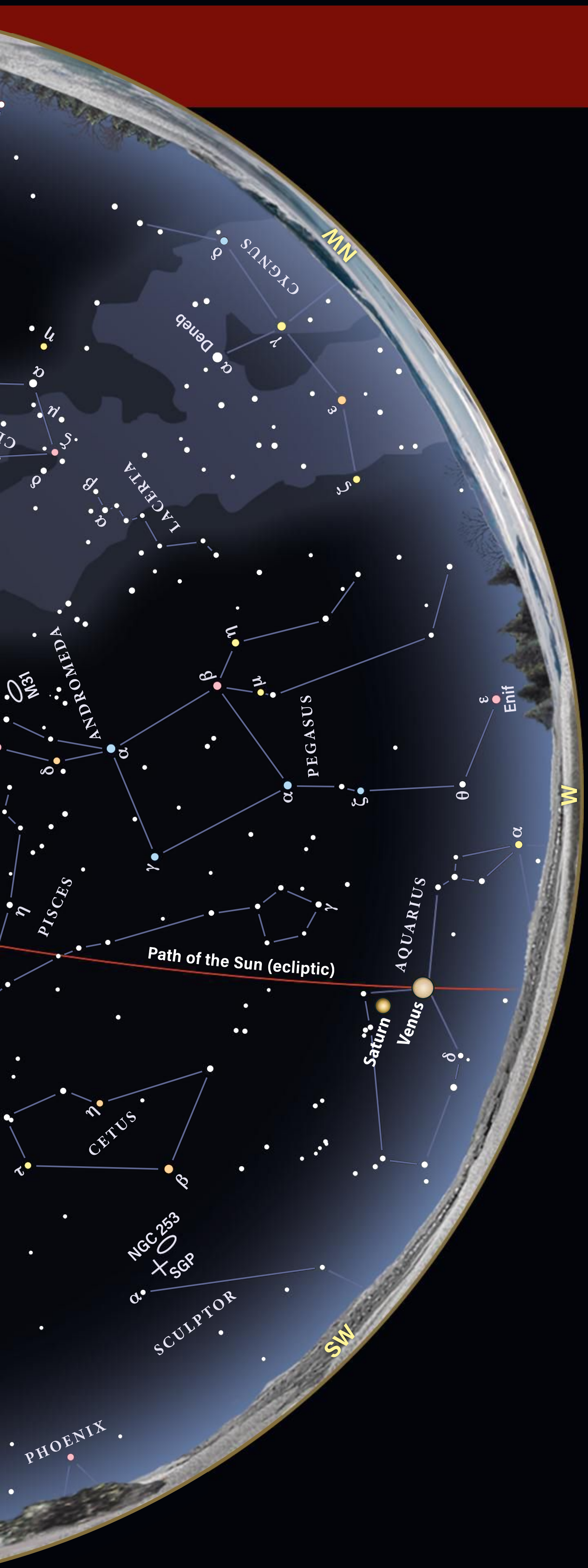
● Sirius
● 0.0 • 3.0
● 1.0 • 4.0
• 2.0 · 5.0

## STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**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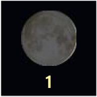
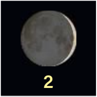
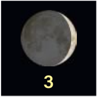
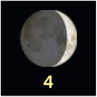
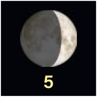
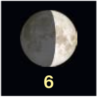
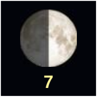
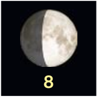
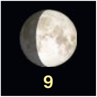
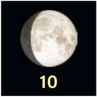
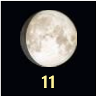
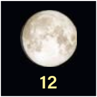
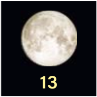
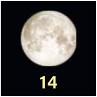
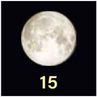
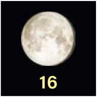
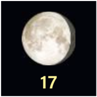
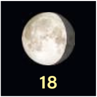
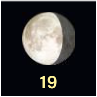
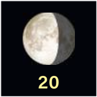
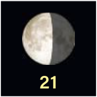
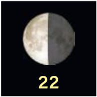
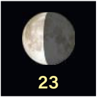
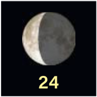
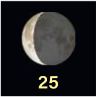
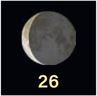
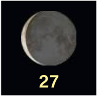
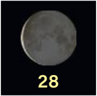
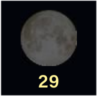
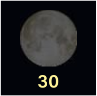
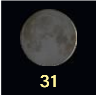
AQUARIUS
PISCES
Path of the Sun (ecliptic)
Saturn
Venus
δ
CETUS
η
ι
β
NGC 253
SGP
α
SCULPTOR
SW
PHOENIX

# JANUARY 2025

| SUN. | MON. | TUES. | WED. | THURS. | FRI. | SAT. |
|---|---|---|---|---|---|---|
| | | | <br>1 | <br>2 | <br>3 | <br>4 |
| <br>5 | <br>6 | <br>7 | <br>8 | <br>9 | <br>10 | <br>11 |
| <br>12 | <br>13 | <br>14 | <br>15 | <br>16 | <br>17 | <br>18 |
| <br>19 | <br>20 | <br>21 | <br>22 | <br>23 | <br>24 | <br>25 |
| <br>26 | <br>27 | <br>28 | <br>29 | <br>30 | <br>31 | |

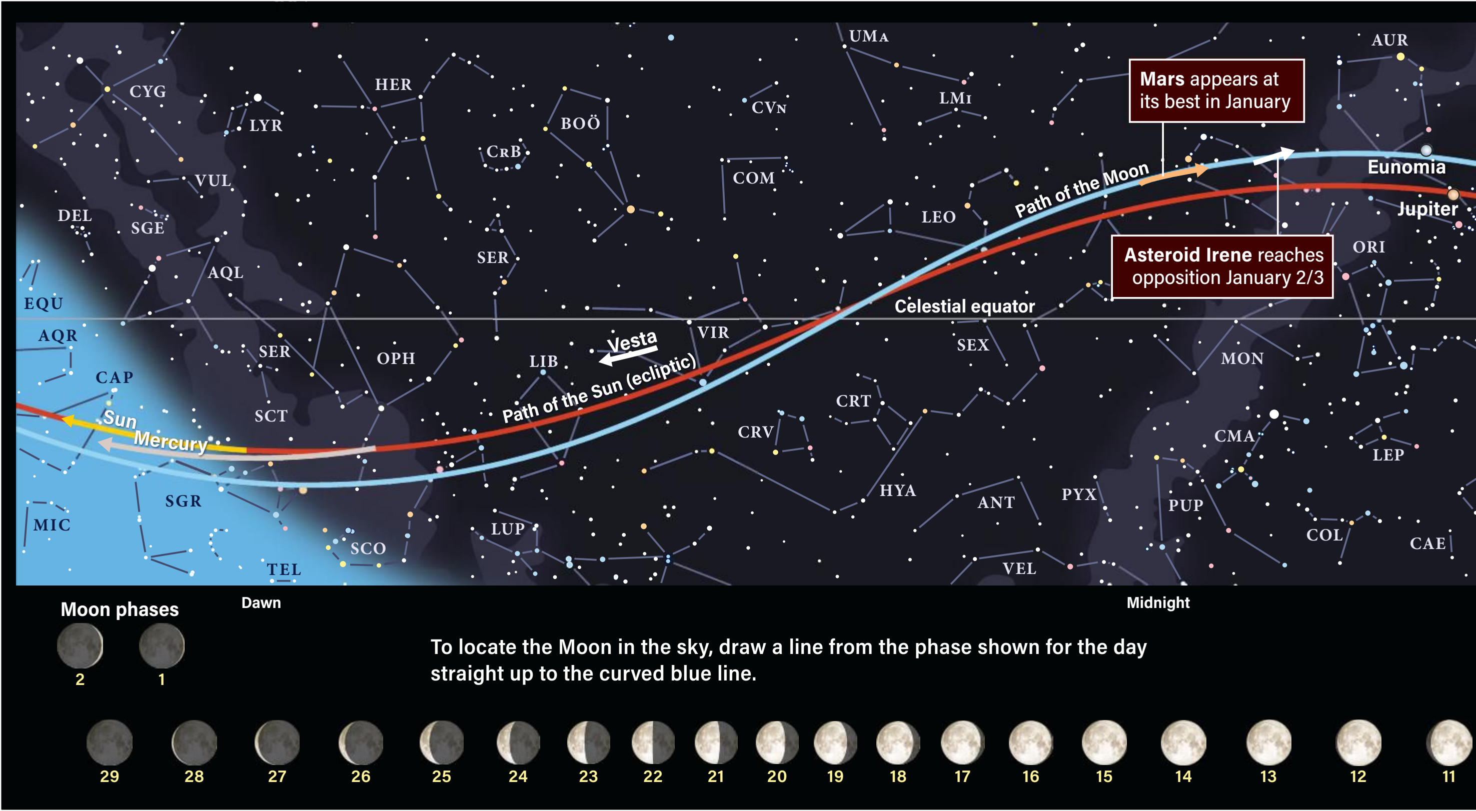
ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**

## CALENDAR OF EVENTS

| | |
|---|---|
| **1** | The Moon passes 1.1° south of Pluto, 7 A.M. EST |
| **3** | Asteroid Irene is at opposition, 2 A.M. EST |
| | Asteroid Pallas is in conjunction with the Sun, 3 A.M. EST |
| | Quadrantid meteor shower peaks |
| | The Moon passes 1.4° south of Venus, 10 A.M. EST |
| **4** | Earth is at perihelion (91.4 million miles from the Sun), 8 A.M. EST |
| | The Moon passes 0.7° north of Saturn, noon EST |
| **5** | The Moon passes 1.1° north of Neptune, 10 A.M. EST |
| **6** | 🌓 First Quarter Moon occurs at 6:56 P.M. EST |
| **7** | The Moon is at perigee (230,013 miles from Earth), 7:01 P.M. EST |
| **9** | The Moon passes 4° north of Uranus, 11 A.M. EST |
| | Venus is at greatest eastern elongation (47°), midnight EST |
| **10** | The Moon passes 5° north of Jupiter, 6 P.M. EST |
| **12** | Mars comes closest to Earth (59.7 million miles away), 9 A.M. EST |
| **13** | 🌕 Full Moon occurs at 5:27 P.M. EST |
| | The Moon passes 0.2° north of Mars, 11 P.M. EST |
| **15** | Mars is at opposition, 10 P.M. EST |
| **19** | Venus passes 3° north of Saturn, midnight EST |
| **20** | The Moon is at apogee (251,219 miles from Earth), 11:54 P.M. EST |
| | The Moon passes 0.1° south of Spica, midnight EST |
| **21** | Pluto is in conjunction with the Sun, 7 A.M. EST |
| | Mars passes 2° south of Pollux, noon EST |
| | 🌗 Last Quarter Moon occurs at 3:31 P.M. EST |
| **24** | The Moon passes 0.3° south of Antares, 7 P.M. EST |
| **29** | 🌑 New Moon occurs at 7:36 A.M. EST |
| **30** | Uranus is stationary, 2 P.M. EST |
| **31** | The Moon passes 1.1° north of Saturn, midnight EST |

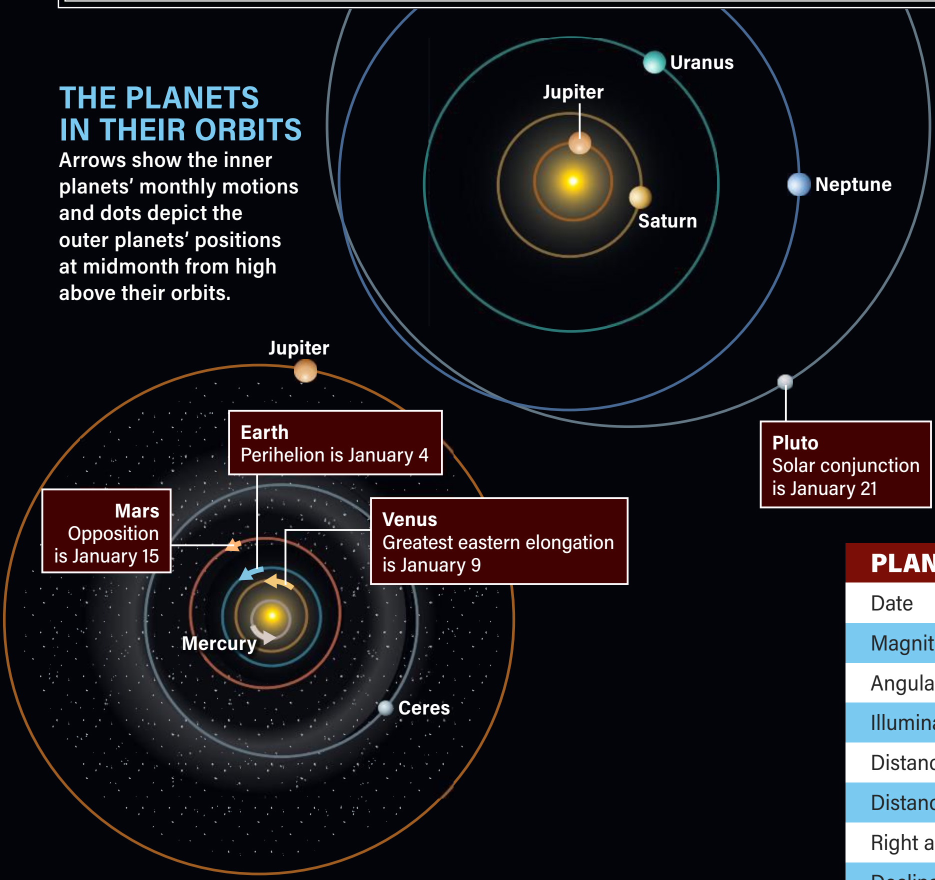
# PATHS OF THE PLANETS


UMa
AUR
CYG
LYR
HER
BOÖ
CVn
LMi
Mars appears at its best in January
CrB
COM
VUL
Eunomia
DEL
SGE
LEO
Path of the Moon
Jupiter
ORI
AQL
SER
Asteroid Irene reaches opposition January 2/3
EQU
Celestial equator
AQR
SER
OPH
Vesta
VIR
SEX
MON
CAP
LIB
Path of the Sun (ecliptic)
Sun
Mercury
SCT
CRT
CRV
CMA
LEP
HYA
ANT
PYX
PUP
SGR
MIC
LUP
COL
CAE
SCO
TEL
VEL
Moon phases
Dawn
Midnight
2
1
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

## THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.


Uranus
Jupiter
Neptune
Saturn
Jupiter
Mercury
Ceres

**Pluto**
Solar conjunction is January 21

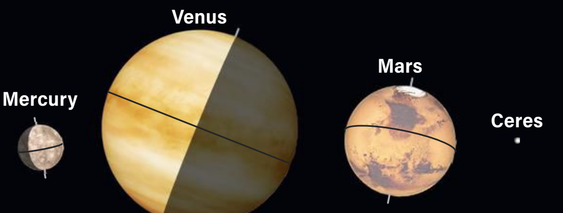
**Earth**
Perihelion is January 4

**Mars**
Opposition is January 15

**Venus**
Greatest eastern elongation is January 9

## THE PLANETS IN THE SKY

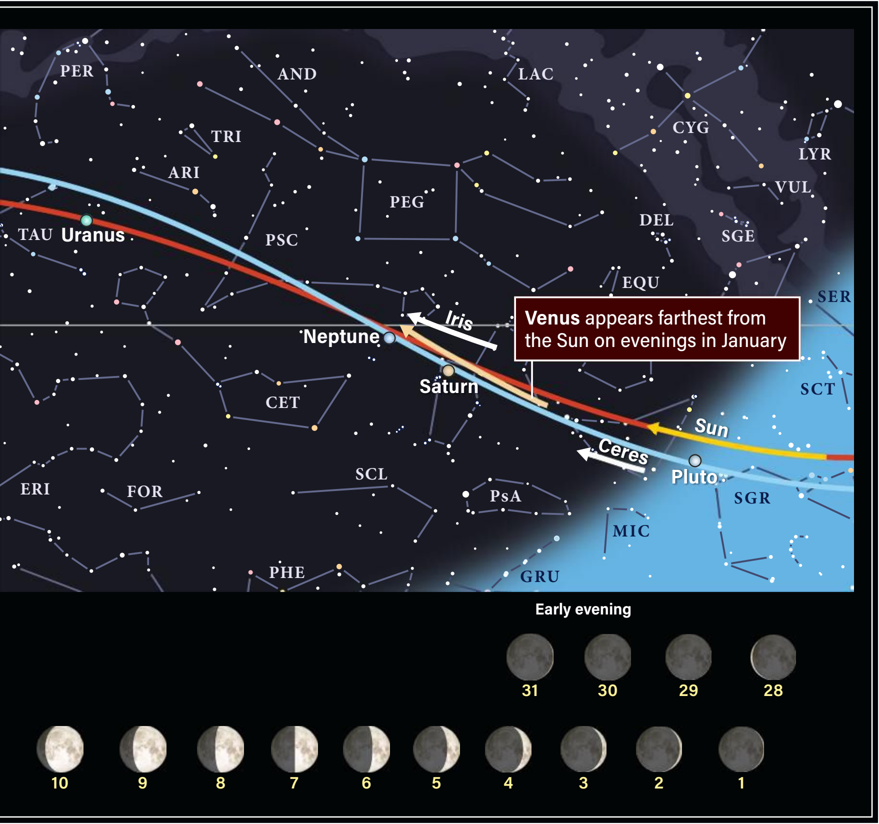
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.


Venus
Mercury
Mars
Ceres

| PLANETS | MERCURY | VENUS |
|---|---|---|
| Date | Jan. 1 | Jan. 15 |
| Magnitude | –0.4 | –4.6 |
| Angular size | 5.9" | 25.8" |
| Illumination | 77% | 48% |
| Distance (AU) from Earth | 1.148 | 0.647 |
| Distance (AU) from Sun | 0.420 | 0.721 |
| Right ascension (2000.0) | 17h14.8m | 22h53.2m |
| Declination (2000.0) | –21°55' | –7°18' |

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

# JANUARY 2025


PER
AND
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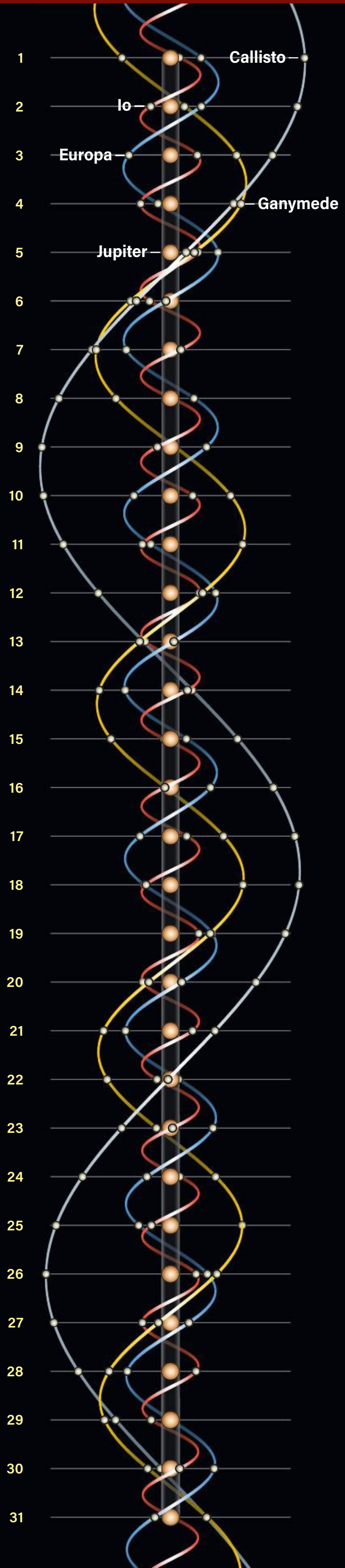
ARI
VUL
PEG
DEL
SGE
TAU
Uranus
PSC
EQU
SER
Iris
Neptune
Saturn
SCT
Sun
CET
Ceres
Pluto
SGR
ERI
FOR
SCL
PsA
MIC
PHE
GRU
Early evening
31
30
29
28
10
9
8
7
6
5
4
3
2
1

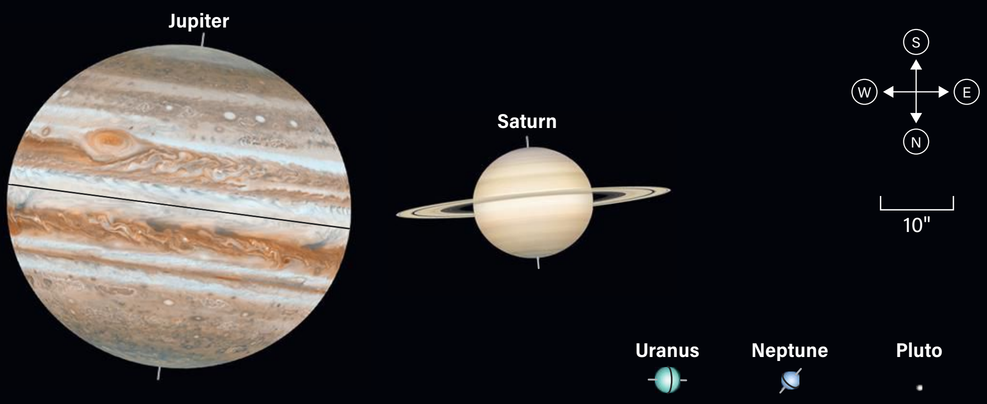
Venus appears farthest from the Sun on evenings in January

Callisto
Europa
Io
Ganymede

## JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EST on the date shown. South is at the top to match the view through a telescope.




Jupiter
Saturn
S
W
E
N
10"
Uranus
Neptune
Pluto

| MARS | CERES | JUPITER | SATURN | URANUS | NEPTUNE | PLUTO |
|---|---|---|---|---|---|---|
| Jan. 15 | Jan. 15 | Jan. 15 | Jan. 15 | Jan. 15 | Jan. 15 | Jan. 15 |
| -1.4 | 9.2 | –2.7 | 1.1 | 5.7 | 7.8 | 15.2 |
| 14.6" | 0.3" | 45.6" | 16.3" | 3.7" | 2.3" | 0.1" |
| 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| 0.643 | 3.881 | 4.324 | 10.220 | 19.066 | 30.336 | 36.156 |
| 1.625 | 2.979 | 5.087 | 9.626 | 19.551 | 29.894 | 35.181 |
| 7h56.8m | 21h14.8m | 4h40.7m | 23h09.1m | 3h22.7m | 23h51.7m | 20h16.7m |
| 25°05' | –23°22' | 21°38' | –7°34' | 18°17' | –2°17' | –23°06' |

18+

WHAT IS

AVAXHOME?

AVAXHOME –

the biggest Internet portal, providing you various content: brand new books, trending movies, fresh magazines, hot games, recent software, latest music releases.

Unlimited satisfaction one low price
Cheap constant access to piping hot media
Protect your downloadings from Big brother
Safer, than torrent-trackers

18 years of seamless operation and our users' satisfaction

All languages
Brand new content
One site

AVXLIVE.ICU

AvaxHome - Your End Place

We have everything for all of your needs. Just open https://avxlive.icu

# SKY THIS MONTH — *Continued from page 29*

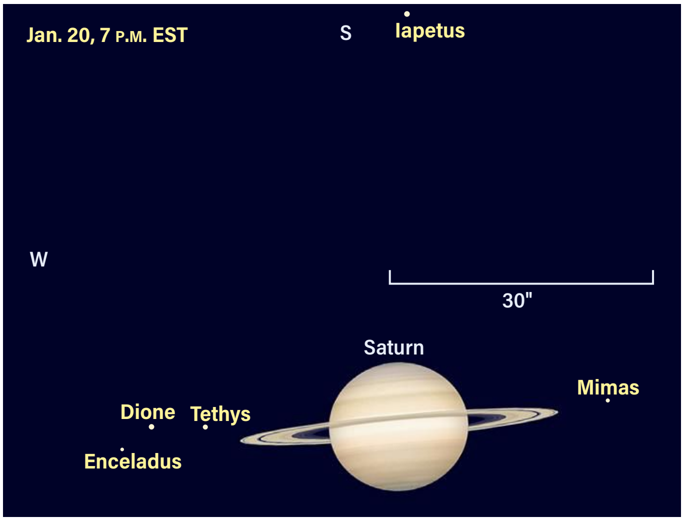
## WHEN TO VIEW THE PLANETS

**EVENING SKY**
Venus (southwest)
Mars (east)
Jupiter (east)
Saturn (southwest)
Uranus (southeast)
Neptune (southwest)

**MIDNIGHT**
Mars (south)
Jupiter (west)
Uranus (west)

**MORNING SKY**
Mercury (southeast)
Mars (west)

**Due south**



On Jan. 20, Iapetus is south of Saturn. Note that Enceladus (12th magnitude) and Mimas (13th magnitude) may be too faint for smaller telescopes.

Europa, Ganymede, and Callisto — are visible; at times one is hidden behind or transiting in front of the disk, along with its shadow.

Jan. 1 sees Io disappear and then re-emerge from Jupiter's vast shadow. The moon vanishes behind the northwestern limb just before 8 P.M. EST. Watch the space 12" east of the planet to see Io appear just before 10:45 P.M. EST.

Around 8:25 P.M. EST on the 6th, Europa begins a transit. Shortly before 10 P.M. EST, its shadow appears. Europa exits the disk at 11 P.M. EST; the shadow exits about an hour and a half later.

On the 16th, Io transits from 8:36 P.M. to 10:48 P.M. EST, with its shadow visible from 9:32 P.M. to 11:44 P.M. EST. As the shadow is exiting the western limb, Ganymede is occulted on the same side almost simultaneously, taking a few minutes to disappear.

Ganymede reappears at the northeastern limb around 1:51 A.M. EST (Jan. 17 in the Eastern and Central time zones). It then drops into Jupiter's shadow 90 minutes later. You'll see it starting to fade just before 3:30 A.M. EST.

Ganymede crosses the disk Jan. 27. East Coast viewers may catch the beginning of the transit at sunset. The moon exits starting around 7:20 P.M. EST. The shadow starts transiting around 9:40 P.M. EST, taking several minutes to fully appear and easily visible in small telescopes. The shadow transit ends beginning at 11:49 P.M. EST.

The highlight of the month is the opposition of **Mars** late on Jan. 15. It peaks at magnitude –1.4, as bright as Sirius. Mars starts January in Cancer and wanders west, entering Gemini by the 12th. This places it high in the sky around local midnight.

Oppositions of Mars occur every 780 days. The planet's diameter reaches nearly 15". Mars' closest approach to Earth occurs Jan. 12, a few days before opposition. It then stands 59,703,891 miles away. (This is an aphelic opposition, not as close as a perihelic one.)

Mars will appear tiny in scopes smaller than 8 inches. Larger scopes provide better views. Be patient and watch for moments when Mars reveals its glory. Do you see the North Polar Hood or the brilliant white polar cap? The former should dissipate this season.

Mars appears to rotate backward when viewed at the same time each night. At 9 P.M. local

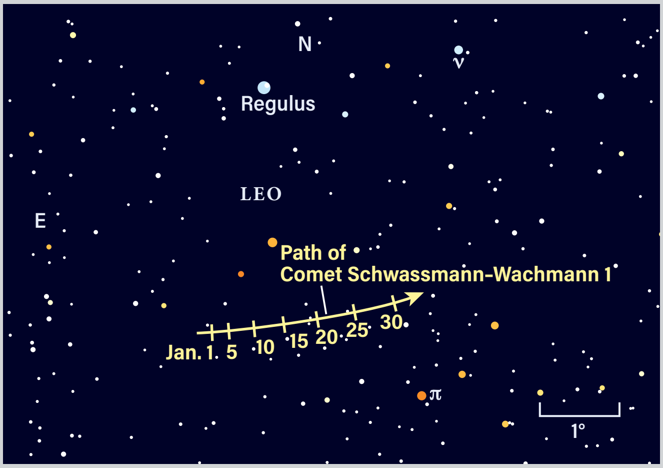
## COMET SEARCH | 2025 starts with hope

**YOU KNOW THOSE** nice comets that burst onto the scene with so little notice they beat the publication deadline? We'd appreciate three of those! This year, no currently known interplanetary snowballs are expected to glow brighter than 10th magnitude or be well placed.

Eager comet hunters with 8-inch scopes can test their skills to reach 333P/LINEAR at magnitude 10.5, but it requires a good star chart and ephemeris to nail it in the starry void. With respect to the North America Nebula (NGC 7000), the faint comet is west of Hawaii.

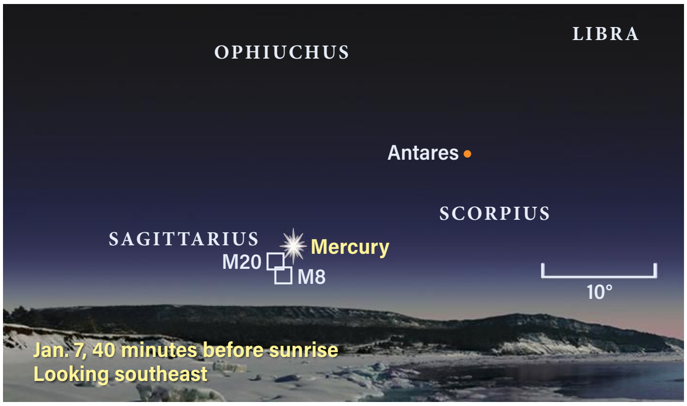
But luck could be ours a short 3° star-hop south of Regulus. Comet 29P/Schwassmann–Wachmann has, semiregularly, outburst from magnitude 15 to 10.5, then taken two weeks to fade back down. You'll want at least 150x for the 1'- to 2'-wide patch to trigger a hit. Practice on the "other" Leo Trio — M105, NGC 3384, and NGC 3389 — the latter of which is a feeble magnitude 11.8, to calibrate yourself before going after the comet.

**Comet 29P/Schwassmann-Wachmann**



Comet 29P/Schwassmann–Wachmann, also called Schwassmann–Wachmann 1, may greet the new year with an outburst in Leo. M105, NGC 3384, and NGC 3389 lie east of this field of view.

### Stars in twilight



Those with a crystal-clear horizon might spot the stars associated with the Trifid and Lagoon nebulae near Mercury the morning of Jan. 7.

time from the central U.S. (look an hour later in the east, and an hour or two earlier farther west), you'll see Olympus Mons and the Tharsis Ridge region facing us in the first week of January. By Jan. 7, Valles Marineris is well positioned, followed a few days later by Solis Lacus. By mid-January, Sinus Meridiani dominates, then Syrtis Major after the 19th, with the bright Hellas basin to its south. During the last few days of the month, Mars shows off Mare Cimmerium.

On the 13th, Mars is occulted by the Moon. Timing depends on location, but the East Coast sees Mars disappear around 9 P.M. EST; this is soon after twilight fades in the Mountain time zone. It takes about 20 seconds for Mars to be fully covered. Along the Pacific Coast, this occurs soon after moonrise in evening twilight. Mars reappears about an hour later.

**Mercury** is visible in the early-morning sky. On Jan. 1 it is an easy object in twilight at magnitude –0.4, 12° east of Antares. It stands 6° high in the southeastern sky by 6:30 A.M. local time.

A week later, you'll need to wait another 15 minutes for it to reach the same altitude. Check the region with binoculars because soon after Mercury rises, you might spot the Trifid (M20) and Lagoon (M8) nebulae 2° east and southeast of the planet, respectively — at least, you might see the stars embedded within them.

There's a lot of uncertainty at the time of writing for the visibility of Comet C/2024 G3 (ATLAS), but it is 5° southeast of Mercury on the same morning (the 7th). Keep watch in case the comet exceeds expectations.

Mercury is less than 1° north of the Lagoon Nebula on Jan. 9, and by the 14th is within 15' of M22, though the 5th-magnitude globular is invisible in twilight.

Mercury attains magnitude –0.5 by the 16th, but its elongation from the Sun has dropped. The planet is lost in twilight over the next few days.

The Moon occults some stars in the Pleiades early on the evening of Jan. 9. The event takes place in darkness on the East Coast and begins in twilight farther west, occurring in daylight for the Pacific time zone.

The 10-day-old Moon tracks across the southern part of the cluster; the first star to disappear from some eastern locations is Electra, around 7 P.M. EST. Just over 20 minutes later goes 4th-magnitude Merope.

From Kansas City, Merope disappears about 6 P.M. CST, but the Moon misses Electra. About 35 minutes later from this location, the Moon reaches Alcyone. Atlas and Pleione are occulted approximately 45 minutes later. The timing is highly dependent on your location; check the International Occultation Timing Association's website (www.lunar-occultations.com) or the 2025 Royal Astronomical Society of Canada's *Observer's Handbook*.

A few 7th-magnitude stars are also occulted, visible in small scopes as they disappear behind the Moon's dark limb.

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***Martin Ratcliffe** is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City. **Alister Ling**, who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

## LOCATING ASTEROIDS

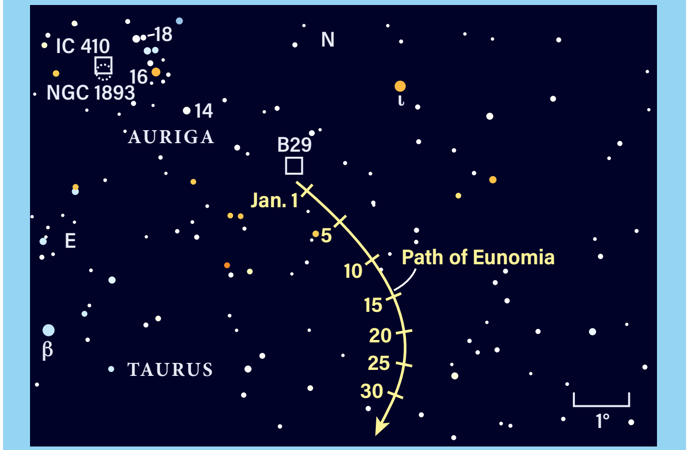
### Wandering down a dark alley

**IF WE LET THEM,** asteroids may lead us along secluded paths that bring us across fascinating fields. From the suburbs, 15 Eunomia is our guiding light, reflecting our Sol to outshine most of the background stars of the outer Milky Way, much of which is obscured by vast, dusty domains. Only three stars are brighter in the vicinity.

Under a dark sky, a realm of stardust and tunnels appears in a wide-field eyepiece. Take your time to identify Eunomia by making a sketch of three or four of the brightest stars and coming back on another night to note its displacement. But the treasure here is found by simply sweeping the scope back and forth across and along the path. Just as easy as many Barnard dark clouds, here lie several Lynds objects.

Over on the south side of Castor on the 15th and cruising at 7' per hour, 887 Alinda appears as a magnitude 9.5 dot that should be fun to follow in a 4-inch scope from the suburbs. Coming within some 30 times the distance of the Moon, this Amor-class rock never crosses our orbit — but it might in millions of years. At a bit more than a mile wide, a hit would mean a regional wipe-out and a global food disaster.

### Dark and light



Eunomia is traveling through a dusty swath of the Milky Way, offering a peek at several dark clouds along the way.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

# A CLUSTER ABOVE ALL OTHERS

JWST exposes Westerlund 1, the Milky Way's most impressive super star cluster.

BY RICHARD TALCOTT

**IN OUR LOCAL GROUP** of galaxies, the star cluster R136 stands out. Located at the heart of the Tarantula Nebula (NGC 2070) in the Milky Way's largest satellite galaxy, the Large Magellanic Cloud, R136 possesses several dozen of the most massive stars known. Astronomers have yet to find another cluster in the universe that holds as many of these stellar behemoths.

Although the Milky Way has nothing to rival R136, it does harbor its own super star cluster. Westerlund 1 contains an impressive array of a few dozen highly evolved massive stars. If the name doesn't ring a bell, it's because the cluster was unknown to scientists until 1961. That's when Swedish astronomer Bengt Westerlund discovered it on a photographic plate taken through a 20-inch Schmidt telescope.

These massive stars shine brightly, so how did they elude detection for so long? The cluster lies some 12,000 light-years from Earth in the heart of the Milky Way, less than ½° south of the galactic plane in the constellation Ara the Altar. Thick clouds of dust and gas block much of the cluster's light, dimming its stars by at least 10 magnitudes. The intervening dust also reddens starlight significantly, converting bright blue stars into fainter, redder ones.

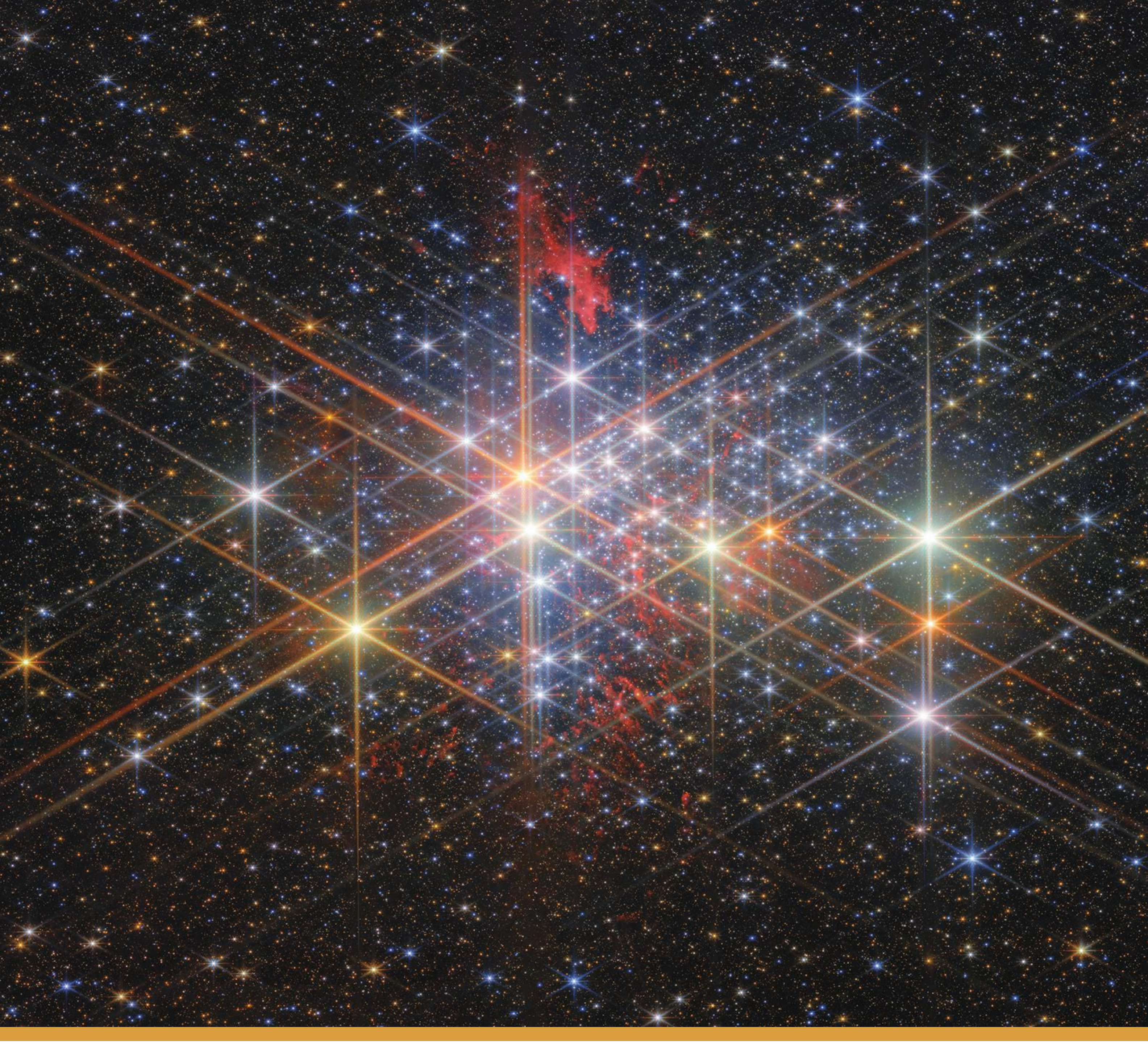
A ground-based visible-light image reveals the thick pockets of interstellar gas and dust that surround Westerlund 1 and redden the light from its stars. ESO/DSS 2

## WEBB TO THE RESCUE

The James Webb Space Telescope (JWST) views near-infrared light, which largely penetrates dust. It sees through the veil that shrouds Westerlund 1 to reveal the stars within as never before. Astronomer Mario Guarcello of the Palermo Astronomical Observatory in Palermo, Italy, led the team exploring Westerlund 1.

The researchers want to understand how the rapid star formation that recently took place there affects the formation of planets and brown dwarfs as well as the evolution of protoplanetary disks. Scientists suspect the intense radiation from massive stars erodes the material in such disks. The cluster mimics the starburst activity seen in merging galaxies and in the early universe. It also opens a window on the hectic early days of our galaxy when it was churning out stars at a fast rate.

The astronomers' first step was to capture Westerlund 1 with JWST's Near-Infrared Camera. The initial image reveals a dense cornucopia of massive young stars. The census includes Wolf-Rayet stars, highly luminous suns that lose mass rapidly thanks to ferocious stellar winds; supergiant stars of spectral



JWST's near-infrared vision resolves Westerlund 1 into a dense cluster of massive stars. Each star boasts six large and two small diffraction spikes, artifacts of the telescope's optics. Patches of glowing red gas appear in and around the cluster. ESA/WEBB, NASA & CSA, M. ZAMANI (ESA/WEBB), M.G. GUARCELLO (INAF-OAPA), AND THE EWOCS TEAM

types O and B (the hottest hydrogen-burning stars); luminous blue variables, highly erratic stars whose brightness and spectra fluctuate dramatically; and yellow hypergiants, the most luminous naked-eye stars that shine nearly a million times brighter than the Sun.

Many of these massive stars eventually will end their lives as supernovae. Astronomers expect the cluster will produce at least 1,500 supernovae in the next 40 million years. And because massive stars live such short lives, scientists estimate that Westerlund 1 must be no more than 5 million years old.

## AN IMPOSING STRUCTURE

The largest of Westerlund 1's stars have diameters more than 1,000 times that of the Sun. If placed at the center of our solar system, such a star would extend to the orbit of Saturn. And if you could reverse this leap of the imagination and place the solar system at the cluster's core, hundreds of stars as bright as the Full Moon would fill our sky.

Westerlund 1 holds 50,000 to 100,000 times the mass of the Sun in a volume less than 6 light-years across. Many astronomers think one day it will evolve from an open cluster into a globular cluster. Although all other Milky Way globulars are ancient, many starburst galaxies hold youthful lookalikes.

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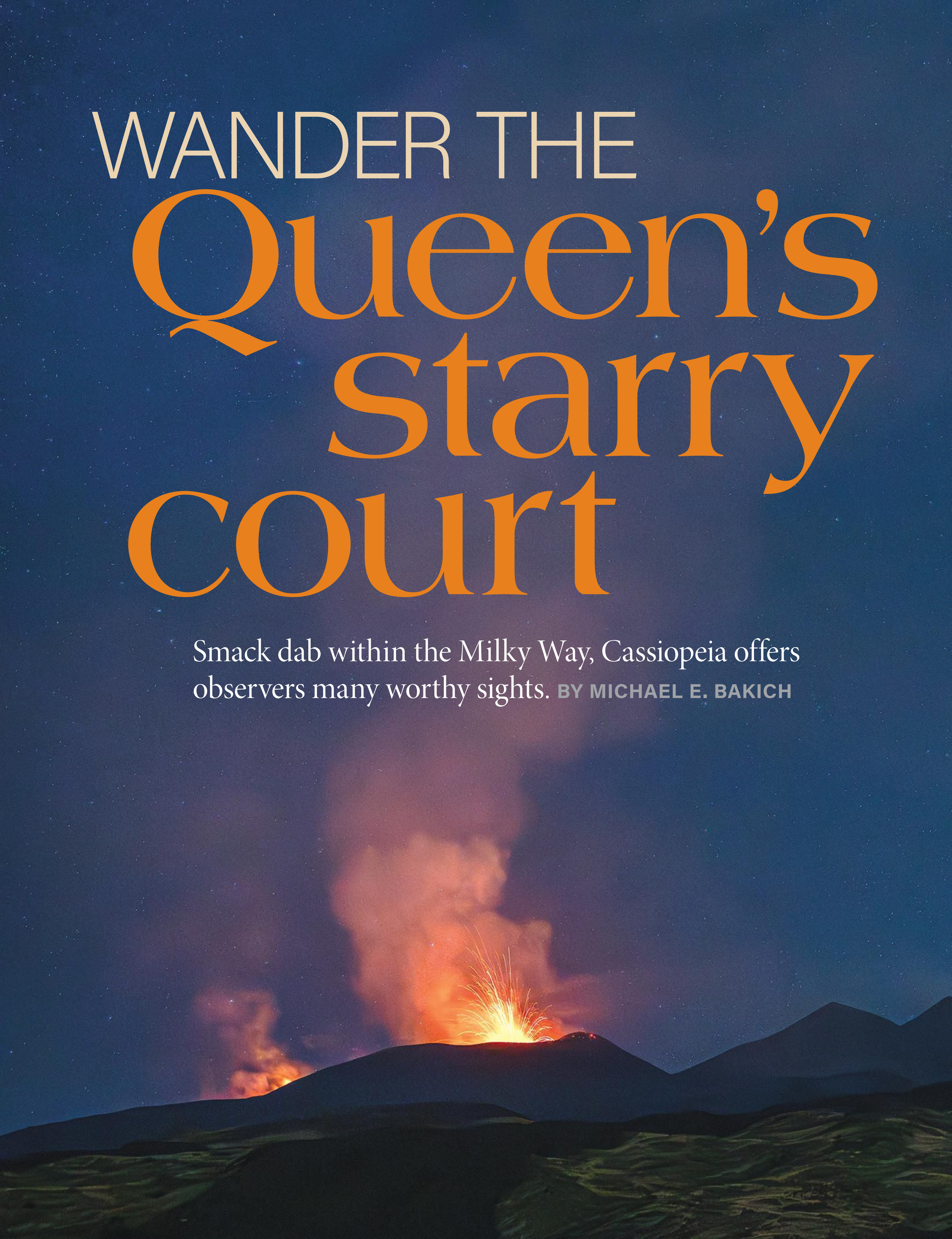
*Contributing Editor* **Richard Talcott** *wrote about JWST's observations of the Crab Nebula in the December issue.*



# WANDER THE Queen's starry court

Smack dab within the Milky Way, Cassiopeia offers observers many worthy sights. **BY MICHAEL E. BAKICH**

**CASSIOPEIA** (pronounced kass ee oh pee' uh) the Queen is one of the first constellations amateur astronomers come to recognize. That's because its five brightest stars form an asterism that looks like a large letter W.

Cassiopeia is observable in the autumn and winter throughout the Northern Hemisphere. It lies opposite the Sun in early October. And if your location on Earth is at 46° north latitude or higher, this constellation is circumpolar, meaning that it will never set.

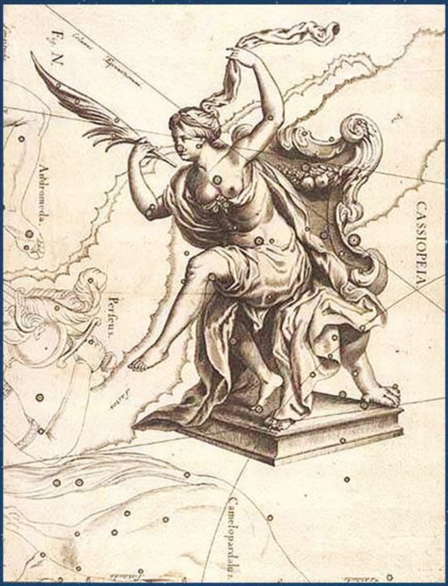
Among the 88 official constellations, Cassiopeia ranks as the 25th largest and 30th brightest. It contains four stars (Alpha [α], Beta [β], Gamma [γ], and Delta [δ] Cassiopeiae) that are among the top 200 brightest in the sky.

## From the west to the east

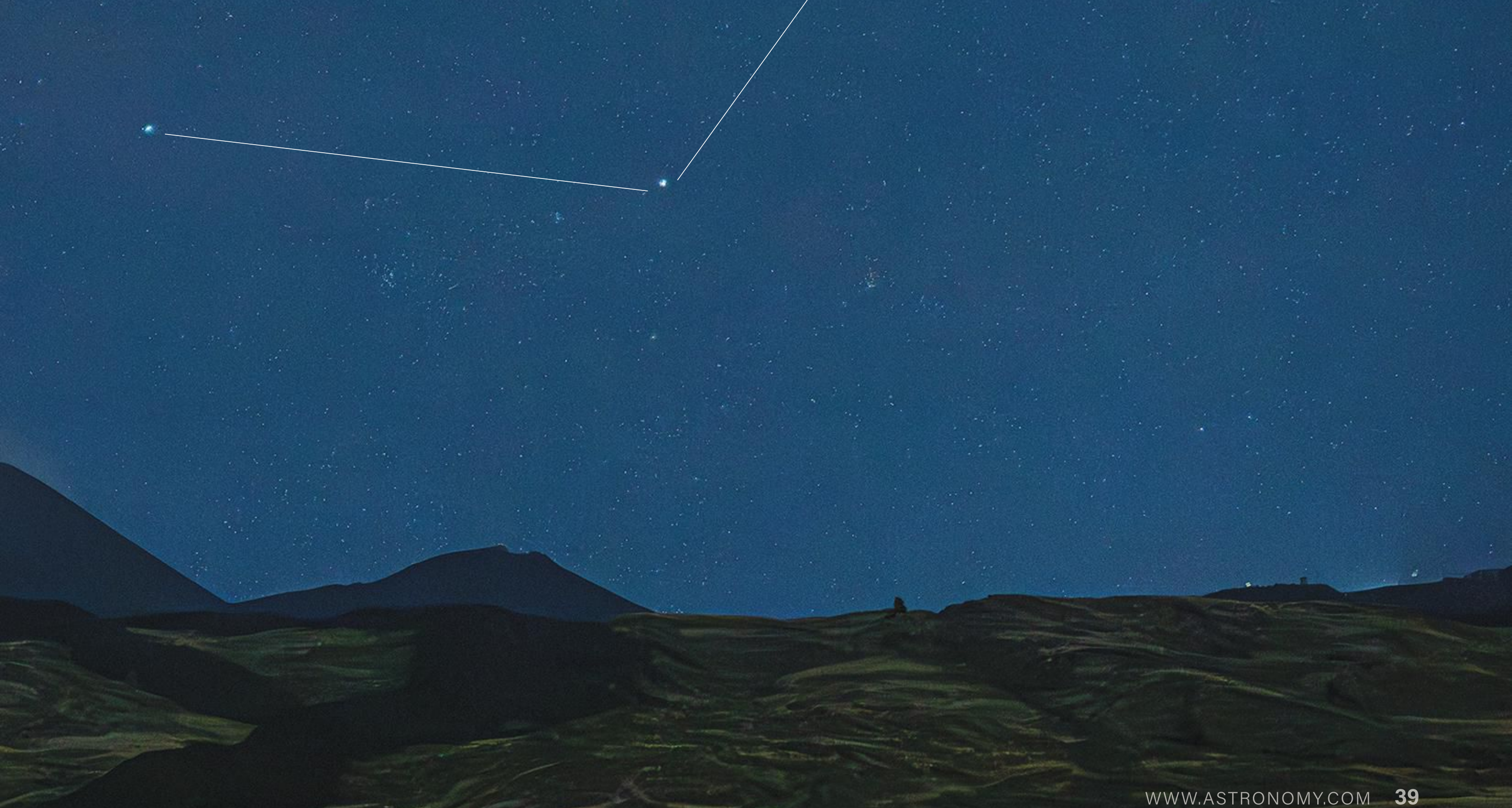
The first target on our list is both famous and difficult to see well: the **Bubble Nebula** (NGC 7635). It's also the 11th object on Sir Patrick Moore's Caldwell list and No. 162 on Stewart Sharpless' list of emission nebulae. The easiest way to find it (without a go-to drive) is to first find the next object on this list, M52, and look a bit more than ½° to the southeast.

The Bubble measures 15' by 8' in angular size and is a favorite target for astroimagers. Through an 8-inch telescope, however, you'll see just a faint arc that measures 3' by 1', surrounding a 9th-magnitude star designated BD+60°2522. This star is more than 40 times the mass of our Sun and emits an intense stellar wind. The outer boundaries of the Bubble are where the edge of the wind is interacting with the surrounding nebulosity.

The Bubble isn't a perfect sphere, of course, because the gas it's expanding into isn't uniform. In some places it's more dense than others. The thickest gas lies to the northeast, which slows the Bubble's expansion in that direction.



ABOVE: In Greek mythology, Cassiopeia the Queen was the mother of Andromeda. Cassiopeia's hubris about herself and her daughter led to a near sacrifice ordered by Poseidon, followed by Cassiopeia being punished to be bound to a throne upside down. WIKIMEDIA COMMONS

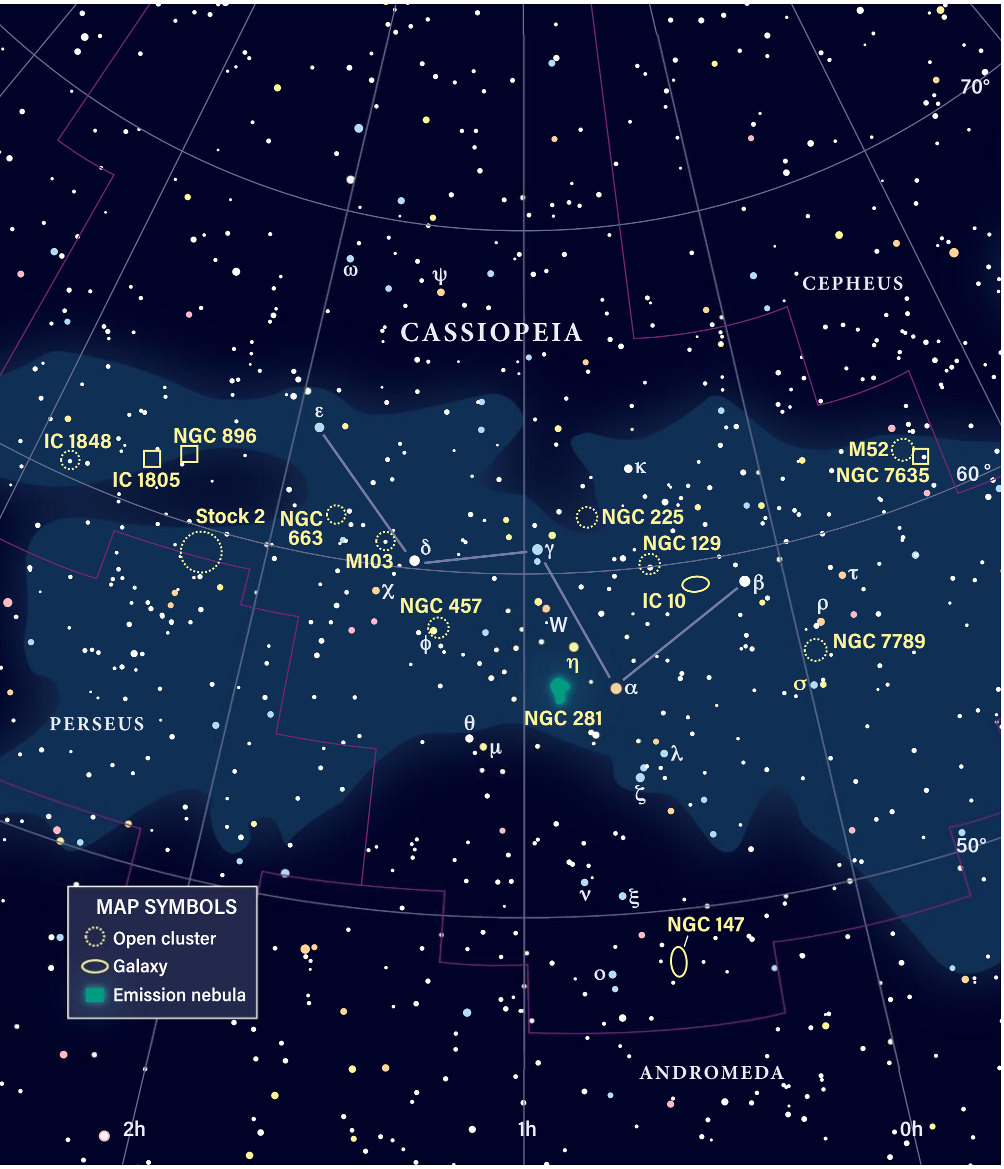


BACKGROUND: Cassiopeia and its distinctive W-shaped asterism rise above the erupting volcano Mount Etna on the island of Sicily, Italy. GIOVANNI TUMINO

LEFT TO RIGHT:
Open cluster NGC 663 contains about 400 bright, blue stars and can be visible to the naked eye on a dark night. The image was taken using a Sky-Watcher Esprit 150 f/7 refractor and a QHY16200A camera. RONALD BRECHER

One of the members of our Local Group is the irregular galaxy IC 10, displaying active star formation. The astrophotographer imaged the galaxy with a QHY600M camera on a Celestron 14-inch EDGE HD telescope. RONALD BRECHER

NGC 129 is an open cluster with a 6.5 magnitude and lies about 5,400 light-years away. You can find it between the bright stars Caph, or β Cassiopeiae, and γ Cas. CHRIS SCHUR


70°
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NGC 281
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50°
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ξ
NGC 147
ο
ANDROMEDA
2h
1h
0h
MAP SYMBOLS
Open cluster
Galaxy
Emission nebula

ASTRONOMY: ROEN KELLY

The result is that the Bubble isn't perfectly centered on BD+60°2522.

A large telescope — 16 inches or larger — is the way to view this object. Through such an instrument, you'll see the entire sphere. Also use a nebula filter, because it will dim the many faint background stars.

The second object on our list is open cluster **M52** (NGC 7654). It glows at magnitude 7.3 and has a diameter of 13'. To find it, begin by drawing a line from Schedar (Alpha [α] Cas) to Caph (Beta [β] Cas) — these stars are 5° apart. Extend the line another 6°, and you'll land on M52.

As with most open clusters on Messier's list, the individual stars are relatively bright and stand out well. In M52, they lie in the 8th- through 12th-magnitude range. An 8-inch scope on a night of good seeing will reveal some 75 members.

Next up is open cluster **NGC 7789**. Because it's so attractive, it has two common names. The first is the Crab Cluster, due to the way famed British observer Admiral William Henry Smyth described it in his 1844 *Cycle of Celestial Objects: For the Use of Naval, Military, and Private Astronomers*. In fact, it is the last object he describes in that two-volume set (probably because its right ascension is 23h57m). Smyth wrote, "It is, indeed, a very glorious assemblage, both in extent and richness, having spangly

rays of stars which give it a remote resemblance to a crab, the claws reaching the confines of the space in view."

The second common name, Herschel's Spiral Cluster, comes from the facts that British astronomer Caroline Herschel discovered it in 1783, and that some of the stars in the cluster form a counterclockwise spiral.

You'll find it midway between Sigma (σ) and Rho (ρ) Cas. It glows at magnitude 6.7 and spans 16'. Use a 4-inch telescope with a magnification around 100x, and you'll be able to count up to 50 stars. Move up to an 8-inch scope and that number will double.

## The first trough

The first double star on our list is **Sigma (σ) Cassiopeiae**. Its components are modest, with magnitudes of 5.0 and 7.2, so an easy way to find it is to look a bit more than 3½° south-southwest of Caph.

The two stars are separated by just 3", so use an eyepiece that will give you a magnification around 150x to split them. Most observers see both stars as white; some see a tinge of blue in them. Human eyes can vary significantly, so the colors you see may be different.

Believe it or not, Cassiopeia does contain galaxies, and our next object is proof. It's irregular galaxy **IC 10**, which you can find by looking 1½° east of Caph.

If you knew nothing about IC 10 and I told you it was 2.2 million light-years away (slightly less than the distance of the Andromeda Galaxy [M31]), you'd probably think, "This has to be a celestial showpiece!" But that's not the case. First, it's only 5,000 light-years across — much smaller than M31 — and second, it's in the Milky Way's plane, so plenty of dust and gas lie within our line of sight.

IC 10 has a magnitude of 10.3 and a size that measures about 7' by 6'. Your best bet to observe it is to point at least an 11-inch scope with a low-power eyepiece in its direction and pan around until you see a gradual brightening of the background. Level up to a 16-inch and you'll start spotting some of the star-forming regions in the galaxy's plane.

The next object is open cluster **NGC 129**, which, at magnitude 6.5, lies right at the edge of naked-eye visibility. You'll find it midway between Caph and a star unofficially named Tsih (Gamma Cas). It's not a small object, sporting a diameter of 21'.

Within that area, an 8-inch scope with an eyepiece yielding 100x will reveal some 25 stars evenly spread out; an 11-inch scope will double that number.

The second galaxy on our list, this time a dwarf elliptical, is **NGC 147**, also known as Caldwell 17. And although it lies within the boundaries of Cassiopeia, it's actually one of the Andromeda Galaxy's satellites. You'll find it roughly 2° west of Omicron (ο) Cas, although spotting it is a bit of a challenge.

NGC 147 glows at magnitude 9.5 — worthy for a galaxy — but that brightness is spread over an area measuring 15' by 9.4'. When scanning the area, do so carefully and look for an oval halo that's a bit brighter than the background glow.

In contrast to faint NGC 147, next up is the impressive **Sailboat Cluster** (NGC 225). To see it, point your scope roughly 2° northwest of Tsih. It glows at magnitude 7.0 and spans 12', half the diameter of the Full Moon. The cluster divides nicely into two starry regions, one a bit fainter than the other.

*Astronomy* contributor Rod Pommier gave this object its common name

ALTHOUGH NGC 147 LIES WITHIN THE BOUNDARIES OF CASSIOPEIA, IT'S ACTUALLY ONE OF THE ANDROMEDA GALAXY'S SATELLITES.

because of its four-star arc that, to him, outlines the leading edge of a sail. A mast of four stars in a line supports the sail. That line connects to a boat outlined by eight stars.

**Achird** (Eta [η] Cassiopeiae) is the second double star on our list, and it's a nice one. The primary glows at magnitude 3.4 and the secondary at magnitude 7.5. The two stars are separated by 11".

If you have trouble locating it, just look 1.7° northeast of Schedar. Low power works best to show the brighter star as yellow and its partner as red. High magnifications accentuate their brightness and make them look white and yellow.

THE PACMAN NEBULA MEASURES A WORTHY 35' BY 30', MAKING ITS AREA ABOUT 20 PERCENT LARGER THAN THAT OF THE FULL MOON.

Next up is the **Pacman Nebula** (NGC 281). You'll find it 1¾° east of Schedar. It measures a worthy 35' by 30', making its area nearly 20 percent larger than that of the Full Moon.

Following the 1980 release of the Namco video game Pac-Man, imagers noticed the nebula's resemblance to the titular character. If you use an 11-inch or larger scope, you will, too. Insert a nebula filter and look for the dark lane that divides the brighter from the dimmer portion. A 7th-magnitude star (Pacman's eye) shines through the brightest part of the nebula.

## What's left of the crown

When you're done with the Pacman Nebula, it's time to observe the **Owl Cluster** (NGC 457). To find it, point your scope 2° south of Ruchbah (Delta Cass). It glows at magnitude 6.4 and has a diameter of 13'.

While observing this cluster in 1977, *Astronomy* magazine Editor David J. Eicher saw an owl figure in the cluster's overall shape, whose eyes were the two brightest stars. He dubbed it the Owl Cluster, and it's carried that name ever since.

NGC 457 is loaded with stars. An 8-inch scope at low power will reveal nearly 100. Its most luminous star, within the cluster, shines at magnitude 8.6. In addition to the cluster, note the uniform background glow caused by distant, unresolved Milky Way stars.

Next up is the second (and last) Messier object in the constellation, open cluster **M103** (NGC 581). To find it, look 1° east-northeast of Ruchbah. It glows at magnitude 7.4 and spans 6'.

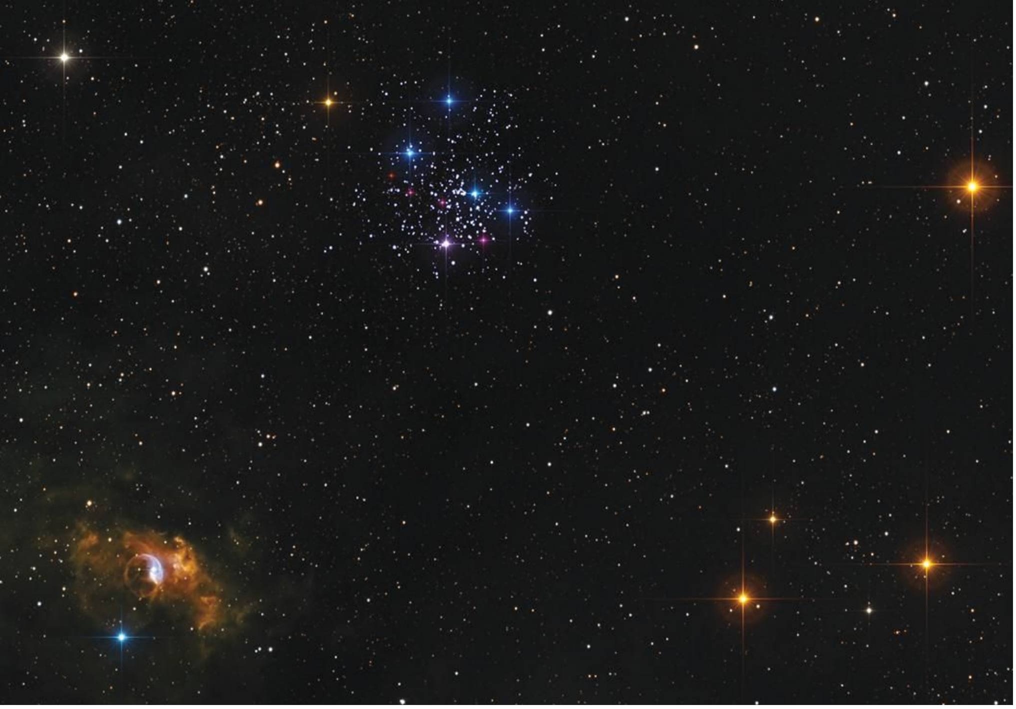
M103 contains three dozen stars with magnitudes between 8 and 13, and together they stand out well from the Milky Way. Most observers see the majority of stars forming a tight triangle. Use a magnification around 100x.

Sometimes, objects appear brighter than their listed magnitudes. That's the case with open cluster **NGC 663**, also known as Caldwell 10. Catalogs show it at magnitude 7.1, but I and other observers have seen it naked-eye from dark sites.

To find this object, first locate the magnitude 5.8 star 44 Cas. Then move ¾° north-northeast. Along the way, you'll pass the 8th-magnitude cluster NGC 659, which I promise you won't see naked-eye.

NGC 663 has a diameter of 16'. If you view it through a 4- to 8-inch scope at a magnification around 75x, you'll see two faint stellar chains, each containing about 20 stars, with a dark space between them. Each chain ends at a pair of brighter stars. View the cluster through an 11-inch scope, though, and the dark space disappears. The star count then approaches 100.

Next, take a look at an object from a different catalog. German astronomer Jürgen Stock compiled a list of 24 open



Both the open star cluster M52 (top) and the Bubble Nebula (NGC 7625; bottom left), were imaged with an 11-inch Rowe-Ackermann Schmidt Astrograph and a QHY600C camera in Pleasant Hill, California. PAUL BRACKEN

clusters in the 1950s. This one, **Stock 2**, glows at magnitude 4.4 and spans a full degree.

To find it, look a bit north of the midway point between Ruchbah and Eta Persei. Although you can see it naked-eye or through binoculars, the best views are through telescopes with eyepieces that keep the magnification below 50x. You'll see a loose collection of some 50 stars in the 8th- to 10th-magnitude range.

In the minds of most observers — and especially imagers — the next two objects go together as a pair. They are the **Heart and Soul nebulae** (IC 1805 and Westerhout 5, respectively). To further complicate things, the brightest part of IC 1805 — a nebulous clump to the northwest — carries its own designation, NGC 896, because it was discovered before the rest of the nebula. Indeed, you'll probably spot it first, too. Also, the energy lighting up the Heart comes from the small open cluster Melotte 15 at its center. And finally, while you'll see lots of references that state the Soul Nebula is IC 1848, that designation belongs to an open cluster within the nebula.

Both of these objects each span 1°, but because the Soul doesn't cover as much area, it appears more condensed. To find the Heart, look 5° east-southeast of Segin (Epsilon [ε] Cas). Once you find it, look another 2½° east-southeast for the Soul.

Because of their size, you can approach observing these objects either with low or high magnification. You will, however, need to use an 8-inch or larger scope from a dark site plus a nebula filter.

For an overall look at the Heart, use an eyepiece that gives about a 1° field of view. Start by identifying the brightest areas: NGC 896, Melotte 15, and the slightly brighter crescent of gas on the western edge.

When you move to the Soul Nebula, you'll immediately see why it's often also called the Baby Nebula. Two large nebulous areas make up the head and body. The head looks denser and contains three faint open clusters cataloged by Swedish astronomer Per Collinder. The body has the star cluster IC 1848 inside. You'll see those stars better if you remove the nebula filter.

As you can see by this list, the Queen contains many objects worthy of a look — a long, highly magnified look.

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**Michael E. Bakich** *is an associate editor of* Astronomy *and loves to spend an entire night observing objects in a single constellation.*

LEFT TO RIGHT:
The several multicolored stars that form M103 — an open star cluster about 10,000 light-years distant — were photographed with Celestron's 8-inch EdgeHD Schmidt-Cassegrain scope.
DANIEL BEAULIEU

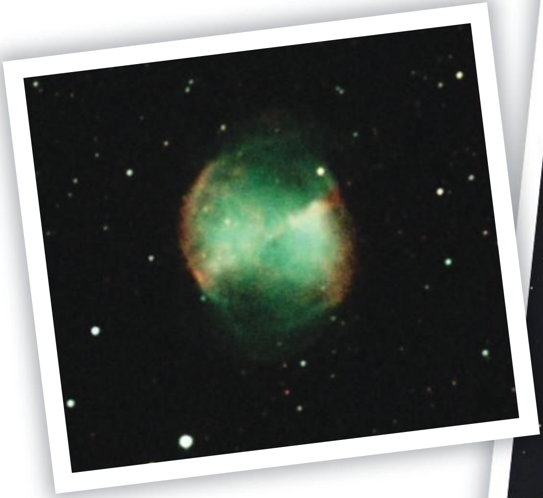
The open star cluster NGC 457, also known as the Owl Cluster, lies 7,900 light-years away from us. An 8-inch Orion f/3.9 Newtonian astrograph with an attached coma corrector was used to capture NGC 457.
JARED BOWENS

The Sailboat Cluster (NGC 225) is another open cluster within Cassiopeia. The gas and dust residing in the cluster have a blue hue due to the hot and young stars inside. LYNN HILBORN

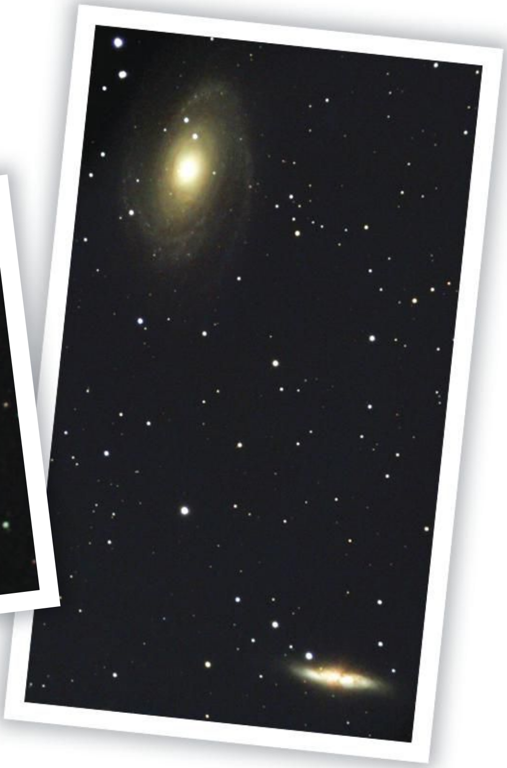
# Astronomy tests the

## Great optics, good portability, and an entry-level price make this scope a winner.

BY PHIL HARRINGTON



Selecting an object like the Dumbbell Nebula will engage the scope's filter. PHIL HARRINGTON



Galaxies M81 and M82 show the field of view of the Seestar S50. PHIL HARRINGTON

**YOU AND I ARE LIVING** through a revolution in amateur astronomy. Not long ago, I would have advised beginners to stay away from astroimaging, because getting good results is both expensive and time consuming. Not anymore. Today, I tell them that state-of-the-art smart telescopes are available at comparatively reasonable prices that let tech-savvy neophytes get incredible results the first night out.

One of the leading contenders in this hot market is the Seestar S50 from Zhen Wang Optical (ZWO). Introduced in April 2023 at New York's North East Astronomy Forum, the ZWO Seestar S50 appears almost too good to be true. It promises that anyone, even with minimal astroimaging knowledge, can capture high-quality images of star clusters, nebulae, galaxies, the Moon, and the Sun. It smooths the steep learning curve traditionally associated with imaging.

The Seestar doesn't look anything like a conventional telescope. The black plastic body is made of two parts: the optical tube and the housing for the alt-azimuth mount and controls. Notably absent is an eyepiece. That's because the Seestar is not made for visual observations. Instead, it's a standalone astrograph designed specifically to photograph the heavens.

The Seestar is built around an apochromatic refractor that sports a 2-inch f/4.9 triplet lens coupled with a Sony IMX462 CMOS sensor. Together, they excel at capturing celestial objects despite the modest aperture. Its apochromatic optics ensure sharp, true-color images, free from common aberrations.

The S50 comes packaged in a form-fitting polystyrene case, which is lightweight and sturdy. It has a small handle and two clips to keep it closed, but lacks a lock and a shoulder strap.

Inside, the Seestar is nestled in its fetal-like "off" position along with a small tripod, a short USB-C charging cable, a brief instruction manual, and a solar filter. Everything is held securely in molded cutouts and weighs a total of 7.8 pounds (3.5 kilograms). By itself, the Seestar weighs 5.5 pounds (2.5 kg).

Two more accessories are hidden inside the Seestar: a dew heater and a dual narrowband nebula filter. The latter improves images of emission and planetary nebulae and will engage automatically when either type of object is selected. The filter may also be engaged manually by the user if desired.

The fully automated Seestar does not come with a hand controller. Instead, to control its operation, the user must download and open the Seestar app on an Apple or Android phone or tablet.

Unless they are permanently mounted in an observatory, most top-end astrophotography setups require a long time to assemble before use. Not the Seestar. It typically takes no more than 10 minutes from opening the case to taking the first shots. That is, unless it is sitting on uneven terrain; if so, it must be leveled according to the app's onscreen instructions. That can add several minutes, although there are third-party tripod attachments that make leveling easier.

To begin, remove it from the case and attach it to the included tripod or one with a 3/8-inch threaded stud. The tripod can be extended from its stowed position of 10.8 inches (274.5 millimeters) to 14.3 inches (363 mm). Some users place the setup on a table, but vibration can be a problem. Instead, I preferred to place it on a sturdy photographic tripod.

Awaken the Seestar by pushing and holding its square "on" button for several seconds, until it says "powering on; ready to connect." Four red battery-status lights below the "on" button indicate the battery's power level. When all four are

# Seestar S50

lit, the battery is fully charged. ZWO states that the battery will last up to six hours, which I found to be a good estimate whether the night is cool or mild. Colder temperatures will diminish the time. In those instances, an external power source can be attached via the USB-C charging port.

Once the Seestar is alive, open the app and connect the two. I found the app to be easy to learn without needing to review included instructions or ZWO's online manual. Be aware that if you do need some coaching, the manual will help, but I would also recommend the plethora of YouTube videos, as well as social media groups such as "Seestar S50 (Official ZWO Group)" on Facebook.

The Seestar announces when it is aligned and ready. From the app, you can view a 24-hour weather forecast, select targets, adjust sound, fine-tune focus, start the anti-dew heater, and toggle the Seestar watermark. Choose exposure times of 10 (default), 20, or 30 seconds for deep-sky imaging, and decide whether to save only the final stacked image or both the stacked image and individual subframes. You should save individual subframes if importing data into software like PixInsight or Siril.

## PRODUCT INFORMATION

**Zhen Wang Optical Seestar S50**

**Type:** Imaging refractor

**Weight:** 7.8 pounds (3.5 kg)

**Size:** 5.6 by 5.1 by 10.1 inches (142.5 by 130 by 257 mm)

**Power:** USB-C/Rechargeable battery

**Battery:** 6,000 mAh

**Price:** $449

**Contact:** ZWO
Moon Bay Road 6#
Suzhou Industrial Park
Jiangsu Province, China
+86-512-6592-3102

After everything is set, the Seestar will silently slew to the target. It worked flawlessly every time, even when aiming at the Sun during the day. The daytime Moon gave it a bit of trouble, however, and was the only time I had to manually aim the scope using the slewing toggle control on the app's screen.

Tapping the red shutter button in the app starts an exposure. Details bloomed on the screen within a minute. Whether it was spiral structure in the Whirlpool Galaxy (M51) or the myriad stars in globular clusters, the Seestar delivered sharp images that continued to evolve until I pressed the shutter button again. Exposures must be started and ended by the user because there's no timer.

Some might think that, with a focal length of only 250mm, the Seestar is a wide-field telescope. It is not. The compact CMOS sensor limits the actual field of view to 1.29° by 0.73°. That can cause some unwanted cropping of expansive targets like the Andromeda Galaxy (M31) and the Pleiades (M45). Adding to this, the sensor has a wide 16:9 aspect ratio (1920x1080 pixels) and cannot be rotated. (The images are displayed in portrait orientation on your phone.) Since there's no way to rotate the view on the alt-azimuth mount, you might have to wait until a different time of night or even a different season for the sky to tilt a target in the right orientation.

During the review, two dark triangles appeared in opposite corners of some images. These were caused by field rotation. The sky moves in an arc, while the Seestar's alt-az mount shifts in steps and rotates subframes to compensate, resulting in the corner anomalies. To fix them, crop the image or adjust brightness and contrast using programs like GIMP, Adobe Lightroom, or even your phone's built-in photo app. Selecting targets near the celestial equator also reduces this.

ZWO's Seestar S50 is an inexpensive, portable imaging telescope that will let you capture images of celestial objects. ZWO

The Seestar S50's out-of-the-box performance is remarkable. Despite not being an experienced deep-sky photographer, I captured amazing images from my light-polluted suburban backyard, even under a Full Moon. The minor issues mentioned earlier don't affect my recommendation. It brought me a renewed sense of excitement and I have been out with it every clear night. For those looking to explore astrophotography, the Seestar is a great investment and just plain fun to use.

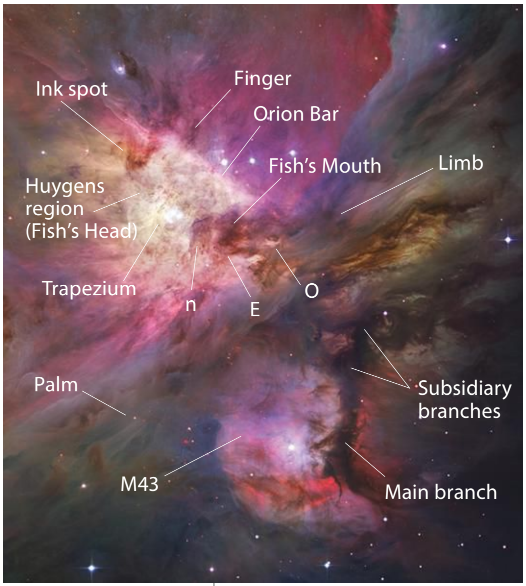
---

**Phil Harrington** *is a contributing editor of* Astronomy *and an expert on equipment for observers and imagers.*

SECRET SKY

# The Dark Orion Nebula

The figures that lie in the shadows deserve just as much recognition as their brilliant counterparts.



The myriad forms that dark nebulae take within and beyond the Great Orion Nebula are accentuated in this Hubble Legacy image. (South is up.) NASA, ESA, M. ROBERTTO (SPACE TELESCOPE SCIENCE INSTITUTE/ESA) AND THE HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM

**BY STEPHEN JAMES O'MEARA**

*Stephen is a globe-trotting observer who is always looking for the next great celestial event.*

Many know the Great Orion Nebula (M42) in Orion's Sword as a bright diffuse nebula — a glowing cloud of cosmic gas illuminated by the Trapezium star cluster. But the Orion Nebula also has a dark side, formed by its lanes and clouds of dust. They frequently avoid scrutiny, as the surrounding brightness tends to steal the show. But you can easily train the eye to reverse the view. It's an illuminating experience that reveals a dark dimension to this familiar object.

M42 is the closest massive star-forming region to Earth, making visual studies of its intricate play of light and dark available to even small telescope users. It's most readily identifiable dusty realms lie between the bright central Huygens region and the neighboring De Mairan's Nebula (M43). The latter is actually part of the same gas cloud that comprises M42; it only appears isolated due to intervening lanes of cosmic dust blocking the light of bright nebulosity beyond. "Nowhere else in the heavens is the architecture of a nebula so clearly displayed," writes Garrett Serviss in his 1901 *Pleasures of the Telescope*.

**You can easily train the eye to reverse the view.**

Let's investigate a few of the more obvious dark nebulae. The most pronounced structure is popularly known as the Fish's Mouth. The Mouth juts into the eastern side of the Huygens region (the Fish's Head), where the 4th-magnitude Trapezium star cluster represents one of the Fish's eyes. The bright parts of the Huygens region lend intensity to the darkness within, owing to a great difference in contrast.

This weblike network is the result of fine wisps and patches of dark nebulosity, superimposed on the scene. If you concentrate solely on the darkness and neglect the bright nebulosity, a powerfully dark image appears. It is a mighty silhouette with a form that can be traced throughout the entire region. Don't rush the view. The longer you look, the more apparent the dark nebulosity should become.

To view this region, I use as high a magnification as possible; that way, even when seen through my 3-inch Tele Vue refractor, fine details manifest in the darkest of spaces. For instance, at a glance, the Fish's Mouth looks like an inky thumbprint. But under powers of 250x to 300x and a prolonged view, the darkness appears segmented into three main parts oriented west-east. With south up, (1) the western section looks like a letter *n*, with finer threads of darkness extending its legs to the north; (2) the middle section appears *E*-shaped with two tiny bright patches peeping through its arms; and (3) the eastern section surrounds an *O* of bright nebulosity, which is so small it looks essentially stellar.

A dark limb of nebulosity extends to the southeast from the lips of the Fish's Mouth. The limb is comprised of several tendrils of darkness, like long grooves of bark. Directly opposite the branch to the northwest is a more delicate wash of darkness. With some imagination, this region resembles the palm of a narrow hand with delicate lines.

This type of wash also caresses the western curl of M43's embryonic form. One thick branch of darkness stretches north-south along the eastern rim of M43 and creates the nebula's embryonic form. See if you can detect its subsidiary branches, as well as small irregularities along the main branch's eastern side that pinch into M43.

Now return your attention to the bright Huygens region. You want to look for a dramatic "ink spot" that lies at the base of a large hedgerow prominence of bright nebulosity erupting to the southwest of the Huygens Region. If you look carefully, you'll find long wisps of darkness extending from it to the south. The longest penetrates the Orion Bar, a wall of dense gas and dust forming the southwest wall of the bright Huygens Region. A parallel finger of darkness lies just northeast of the long wisp.

Finally, see if you can see the dark well in which the Trapezium lies. Stellar winds from the four hot massive Trapezium stars have created a vast cavity in the surrounding dust and gas, allowing us to see them clearly.

As you explore the dark Orion Nebula, keep in mind that you are exploring territories few have bothered to visually tread — at least in fine detail. As always, send what you see or don't see to sjomeara31@gmail.com.

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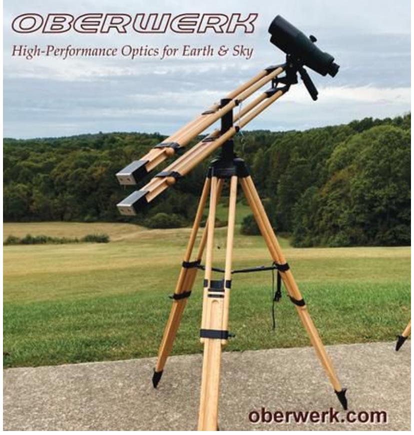

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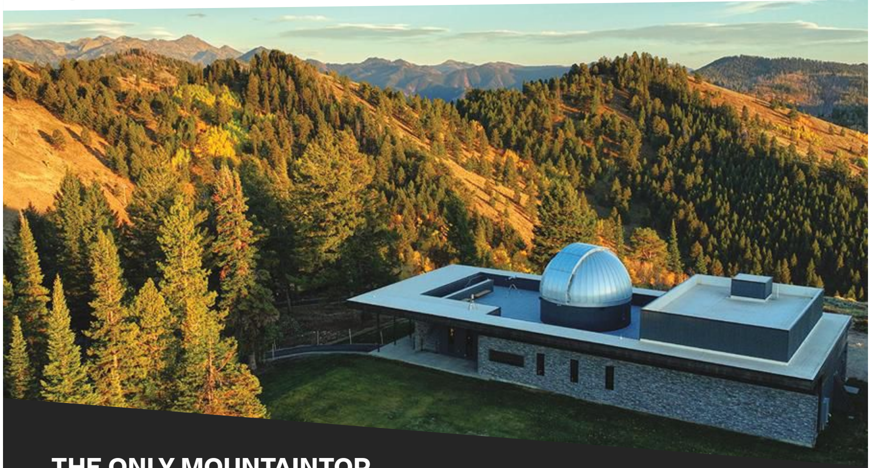

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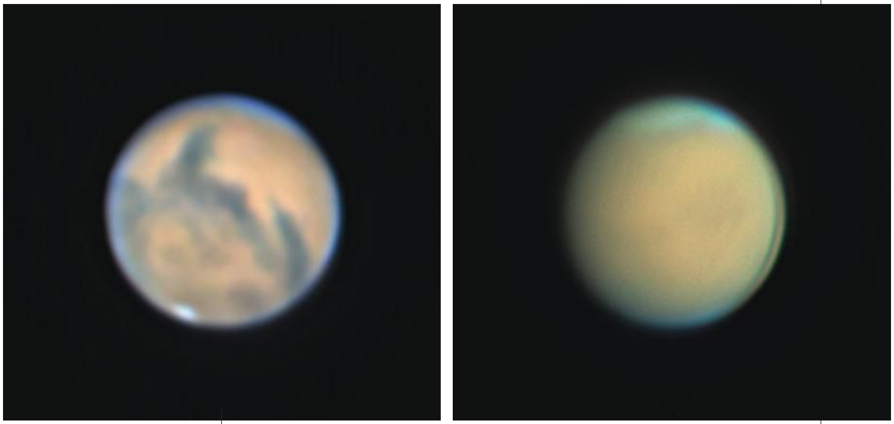
# Mighty Mars at opposition

The Red Planet looms large.



LEFT: A tiny ice cap is visible at the bottom of Mars in this view through my Celestron 8-inch SCT Oct. 11, 2020. The dark peninsula at top is Syrtis Major Planum.

RIGHT: The 2018 dust storm lasted from June until September. I took this shot June 27, about a week after the storm encircled the planet, with my Celestron 8-inch SCT. You can just make out Valles Marineris, a 2,500-mile-long canyon, near the center. MOLLY WAKELING (2)

**BY MOLLY WAKELING**

*Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.*

At public stargazes and evenings with friends at the telescope, we love to set our eyes on the wonders of Saturn and Jupiter at every opportunity. Year-round, whenever they're above the horizon, they never cease to amaze. Mars, on the other hand, is easy to underappreciate because it appears small for much of the year, making it hard to pick out the kind of detail you can see on the gas giants.

But every 26 months, the orbits of Earth and Mars allow us a closer look at the Red Planet when Mars is at opposition — which will happen on the night of Jan. 15 this year. In the early evening, Mars will be easy to locate: It will be the bright, ruddy, starlike object just below Castor and Pollux, the twin stars of Gemini, almost due east. It rises quickly and will be nearly overhead at midnight for the southern U.S., and still high for the rest of the country.

**Mars is also known for its dust storms, which can sometimes encircle the whole planet.**

While you can see Mars as a tiny disk through binoculars, a telescope is necessary for garnering any detail. When it comes to planets, long-focal-length instruments are your friend — my favorite for viewing planets is my Celestron 8-inch Schmidt-Cassegrain, clocking in at 2,032 mm focal length. How much magnification you can throw at Mars will depend strongly on your local seeing conditions — that is, the steadiness of the atmosphere. If the seeing is good, go for your highest magnification eyepieces or use a Barlow lens with a lower power.

For nights of average seeing, a good rule of thumb is to use a magnification between 30x and 50x times the aperture of your telescope in inches. For example, with my 8-inch scope, 240-400x should work nicely, which means I'll use 5mm to 8.5mm eyepieces. A humble Plössl — not the most complex of eyepiece designs — can deliver satisfying views. Give some color filters a try as well, if you have them, to bring out different features. Just don't expect to see color.

When observing Mars, there are three main features that are immediately evident: light-red dusty regions, darker areas of exposed volcanic rock, and the white polar ice caps. Early astronomers named the lighter regions like land masses, such as Elysium Planitia (the Elysium Plain), and named the darker regions like bodies of water, such as Mare Tyrrhenum (named for the Tyrrhenian Sea in the Mediterranean). The polar ice caps wax and wane with the martian seasons, and our ability to see them is also affected by Mars' tilt, but I find them the most exciting to spot. With some diligence and a map of Mars, you can ascertain which features you are looking at. I use the SkySafari smartphone app to see what is currently visible by zooming in on Mars and tapping its features. The Red Planet rotates once every 24 hours 40 minutes, so observing it through the night will reveal different features, as will watching it over the course of a few weeks.

Mars also has more transient phenomena. Despite having a much thinner atmosphere than Earth, clouds do form on Mars, particularly over the large basins. The martian volcanoes also tend to attract them. Use a blue or violet filter to see the clouds more easily.

Mars is also known for its dust storms, which can sometimes encircle the whole planet — as happened in 2018. When this occurs, Mars appears light red and featureless for weeks or even months. The 2018 storm killed the Opportunity rover 5,352 sols (martian days) into its mission. These storms change the look of the martian landscape, which is why maps of the fourth planet from decades ago look different than current ones.

There are many exciting features to enjoy when gazing at Mars; one can really get the sense of how similar the dusty planet is to our own. If you can't observe it right at opposition, don't worry — it will remain large and bright for several weeks as its distance from Earth increases. I personally enjoy listening to Gustav Holst's "Mars, the Bringer of War" while watching it through my telescope. Happy Mars opposition!

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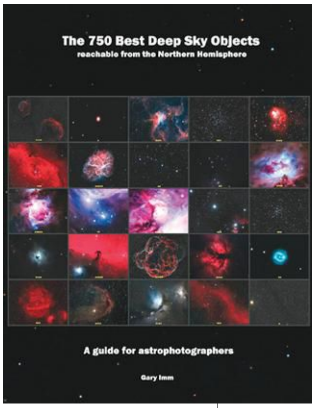
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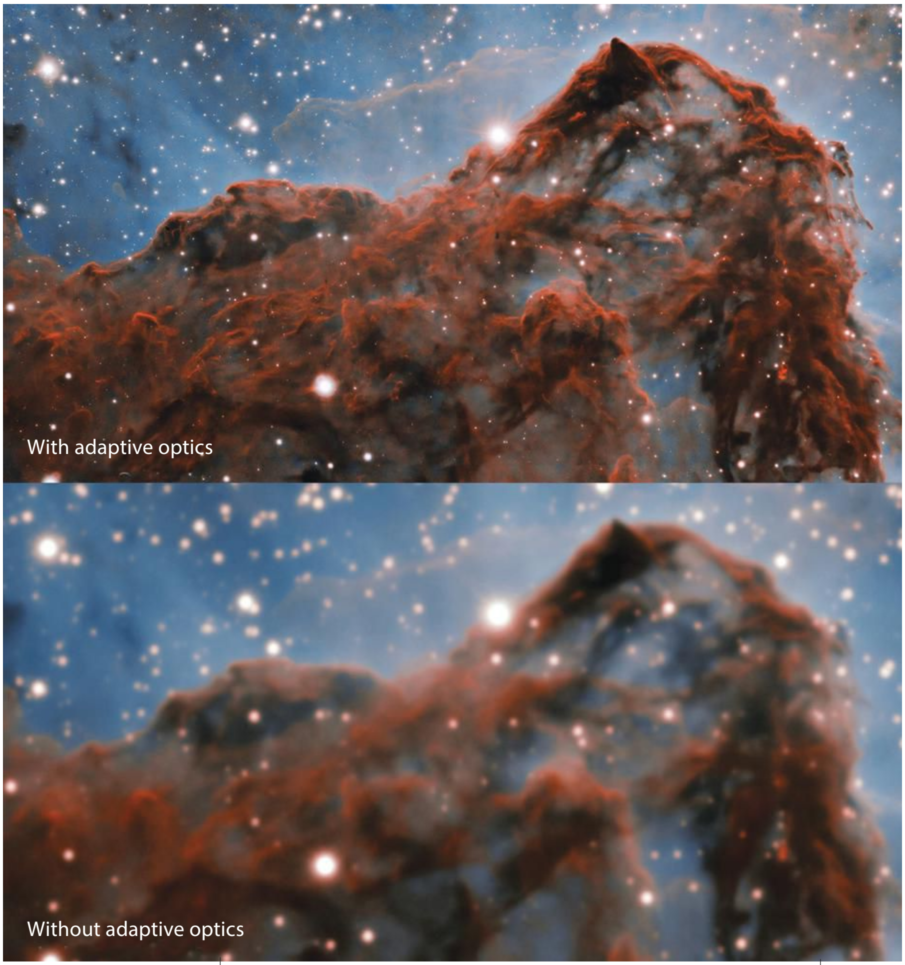


This pair of photos shows the same region of the Carina Nebula, imaged with (top) and without adaptive optics. The top image was taken using the 8.1-meter Gemini South Telescope, using its Gemini Multi-Conjugate Adaptive Optics System; the bottom was obtained with the 4-meter Víctor M. Blanco Telescope. INTERNATIONAL GEMINI OBSERVATORY/CTIO/NOIRLAB/NSF/AURA. ACKNOWLEDGMENT: PI: PATRICK HARTIGAN (RICE UNIVERSITY). IMAGE PROCESSING: PATRICK HARTIGAN (RICE UNIVERSITY), TRAVIS RECTOR (UNIVERSITY OF ALASKA ANCHORAGE), MAHDI ZAMANI & DAVIDE DE MARTIN

# Adaptive optics

**Q** COULD A TELESCOPE BE VIBRATED WITH THE RIGHT FREQUENCY TO COUNTER THE ATMOSPHERIC TWINKLE OF STARS?

***Robert Byerly***
*Windsor, California*

**A** Yes, it can! This is one facet of adaptive optics, which astronomical observatories can use to compensate for distortions in astronomical images caused by our atmosphere.

Let's set the stage first: Stars twinkle because on Earth, we are observing them through air. Air is a fluid, just like water, and its turbulent motions distort incoming light, much like the way objects at the bottom of a pool or a pond appear distorted when you peer down at them.

So, adaptive optics are designed to do just that: adapt to the changes in the atmosphere to essentially "undo" the turbulence and create sharp, undistorted images. Professional observatories do this not by vibrating the telescope, but by subtly deforming the surface of the telescope's mirror in exactly the right way to correct or "straighten out" the jumbled, distorted images they receive through the atmosphere.

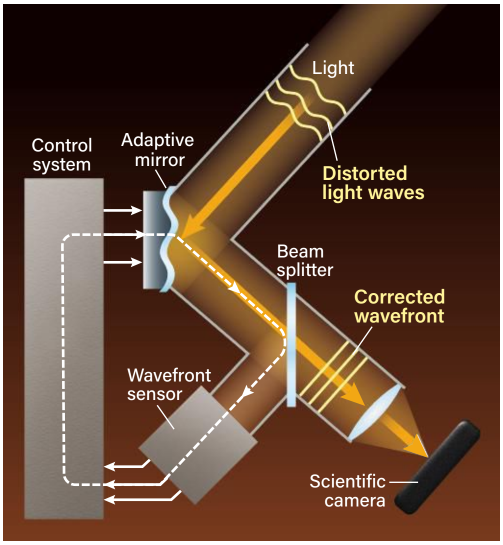
Deformable mirrors are built with many tiny actuators, which push or pull on the mirror's surface, spread across the backside of the mirror — typically the secondary. A specialized computer system that incorporates a device called a wavefront sensor then detects the "shape" of incoming light waves and determines in real time how to deform the mirror to compensate. This is often done using a laser guide star, a strong laser beam shot into the sky that provides a "perfect" example star whose distortion is measured so that the system can correct for it. Essentially, the system knows what a laser spot on the sky *should* look like, so it measures the ways in which the observed spot differs and calculates how to change the mirror's surface so it will reflect a perfect spot, as expected. Adaptive optics systems generally run at about 1,000 hertz, meaning measurements and corrections are made about 1,000 times a second.

The secondary *can* also be tilted or rotated to make additional adjustments as well — this is a more limited correction than deforming the mirror (though more like the vibrations you suggest) but is still often used in tandem with the deformable mirror for additional image correction.

Adaptive optics systems are now available for use on many major professional telescopes, though there are, as always, limitations. The region of the telescope's field of view that can be corrected is usually much smaller than the entire field it is capable of seeing, although there are newer, more complex techniques that use multiple lasers or mirrors to improve this. These systems also historically operate in optical wavelengths, though their use in infrared observations is improving and increasing.

Additionally, unless a telescope can generate its own laser guide star, astronomers must rely on a bright field star near the object they want to observe to use as a guide, which is not always available. Observatories that do use laser guide stars typically have aircraft detection

## ADAPTIVE OPTICS SYSTEMS



An adaptive optics system measures the distortion of incoming light and compensates to create sharp, clear images. Light from the telescope bounces off the adaptive mirror and is sent through a beam splitter, which divides it into two beams. One beam (bottom left) is sent to a wavefront sensor, which measures the distortion of the light caused by its journey through Earth's atmosphere. A control system uses this information to subtly deform the adaptive mirror to compensate. The resulting corrected light is sent to the telescope's camera for scientific imaging (bottom right). The system is iterative, with wavefront measurements and mirror corrections occurring some 1,000 times a second.

*ASTRONOMY*: ROEN KELLY, AFTER C. MAX

systems built in to ensure that the laser never crosses the path of any planes flying overhead; if the safety system is not working or there is an aircraft passing by, the laser guide star cannot be used.

***Alison Klesman***
*Senior Editor*

**Q** EARTH SPINS AS IT ORBITS THE SUN, AND THE SOLAR SYSTEM IS ORBITING THE GALACTIC CENTER. SO, IF I GO OUTSIDE AND LOOK UP, IN WHAT DIRECTION ARE WE HEADING?

***Dale Peterson***
*Oak View, California*

**A** When you gaze up at the constellation Hercules, you are looking out the front window of the spacecraft called Earth. Our planet is hurtling at some 45,000 mph (72,000 km/h) toward the star Lambda (λ) Herculis, which lies about 370 light-years away. (Textbooks often state the bright star Vega, to generalize the direction.)

At this speed (and if Lambda Herculis remained in the same position), it would take some 5.5 million years to reach this point in space; it's not worth thinking about, so just enjoy the ride.

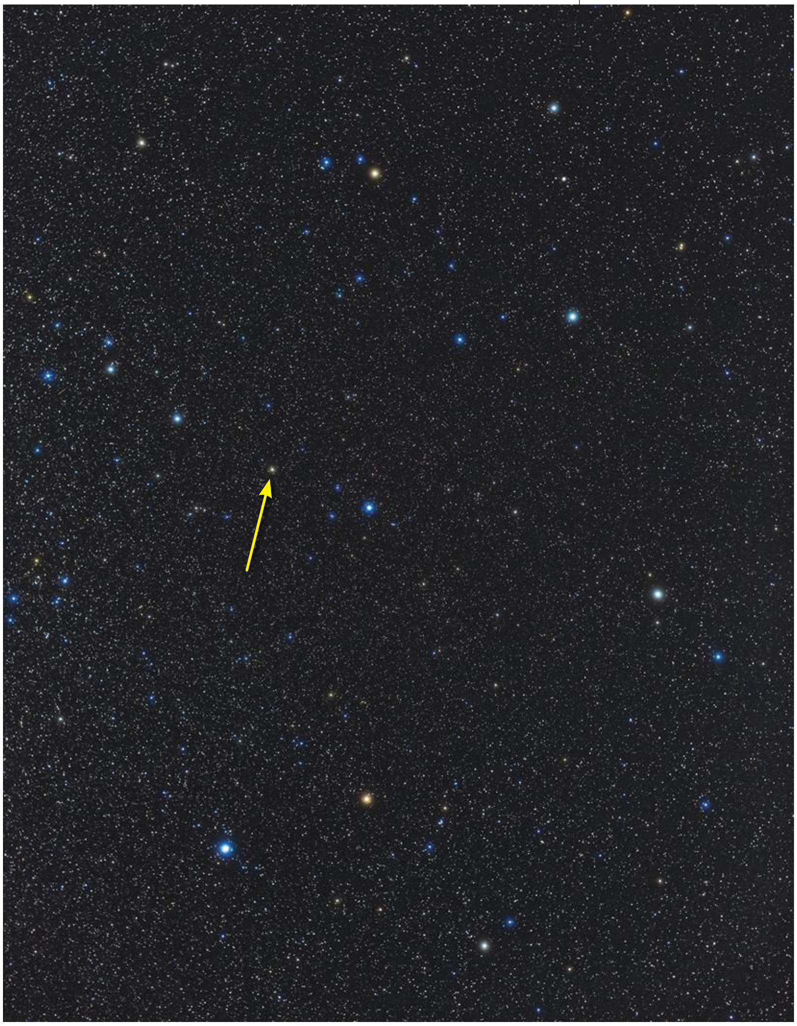
The Sun, the planets, and all the other flotsam and jetsam that constitute the solar system are so insignificant that we can consider the entire mass a point in space. No matter where you might stand — on the Moon, Jupiter's Io, Pluto, or any location on Earth — you are still traveling in the same direction.

We accept that our planet spins on its axis once a day almost as a matter of faith. Earth and the Moon gyrate around the Sun, completing a full orbit in approximately 365 days. Our planet experiences many other motions, such as precession and nutation, but none has any impact on the inexorable flight toward Lambda Herculis.

There's more! The Sun and its attendant bodies slowly bob up and down through the Milky Way's arm. Our planetary system also orbits the galactic center about every 220 million years. And don't forget that our galaxy is likely on a collision course with the Andromeda Galaxy (M31). Our entire local cluster of galaxies is also in motion. The best part: no motion sickness.

***Raymond Shubinski***
*Contributing Editor*

If you look up at the constellation Hercules, you are looking in the direction Earth (and the entire solar system) is traveling. Specifically, we are headed toward the star Lambda Herculis, marked with an arrow. ALAN DYER



Several bright jets spew from the surface of Comet 67P/Churyumov-Gerasimenko as ices on the nucleus turn to gas. This image was captured Aug. 12, 2015, by ESA's Rosetta spacecraft. On this date, the comet was just one day prior to perihelion, its closest approach to the Sun.

D. ROMEUF (UNIVERSITY CLAUDE BERNARD LYON 1, FRANCE). IMAGES: ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

## Q | DO THE PERIODS OF COMETS DECREASE BECAUSE THEY LOSE MASS EVERY TIME THEY GET NEAR THE SUN?

***Robert Bailey***
*Conover, Wisconsin*

A | Great question! Assuming you're referring specifically to the orbital period — in other words, how long comets take to make one revolution around the Sun, or a cometary "year" — according to basic physics, the period of an object does not depend on the mass of that orbiting object, and instead only on the size of the orbit and the mass of the central body being orbited (in this case, the Sun). So, if some of a comet's mass suddenly disappeared one day, its orbital period should remain unchanged.

In the real world, however, mass does not simply disappear — it has to go somewhere. In a comet's case, ice turns into gas when heated by the Sun, and that gas escapes into space (a process called outgassing), usually also carrying away some amount of dust along with it.

Cometary outgassing carries mass and momentum away differently on different comets, depending on their circumstances. For some comets, gas and dust might escape more or less evenly over the comet's entire surface, like a melting ice cube. In other cases, gas and dust may escape from a specific location in a preferred direction, like a balloon that's been blown up, but not tied off, and then released. The escaping material can cause significant changes in a comet's orbit, acting like natural rocket engines, with the exact changes depending on the direction, speed, and amount of the escaping gas and dust.

For this reason, astronomers regularly look for orbital changes each time comets return near the Sun and update those orbits as needed, leading to reference catalogs listing multiple orbits for some comets, corresponding to each return if the changes are large enough. Besides having the practical benefit of keeping comet orbits updated so that we can continue to accurately predict when and where they will appear in the sky, tracking orbital changes during close approaches to the Sun is also of scientific interest to comet researchers because it provides a means for indirectly tracking the evolution of the strength and other details of a comet's outgassing over time.

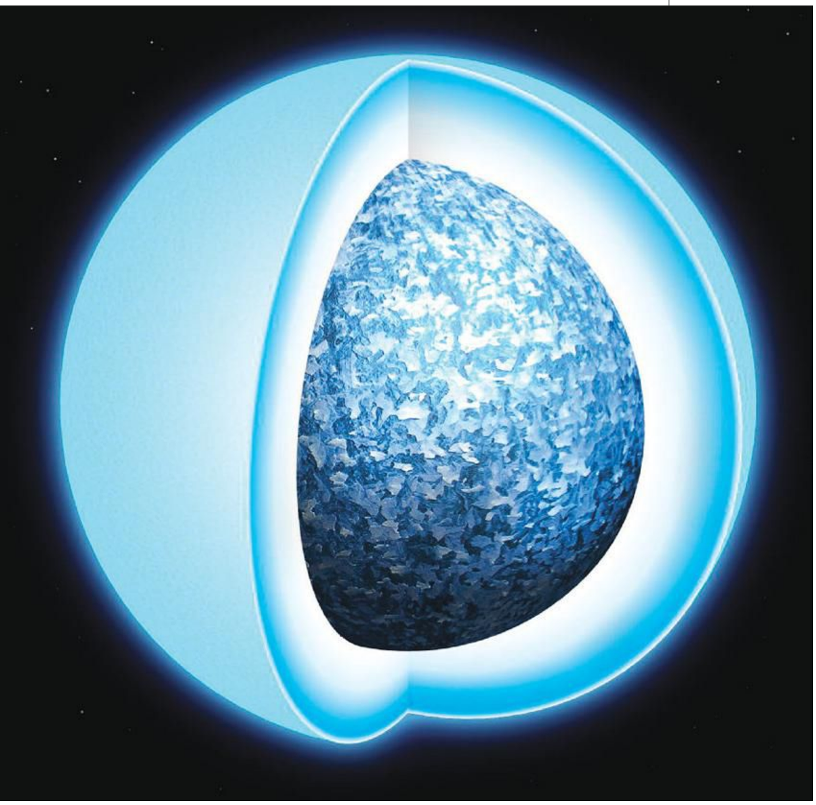
With regard to your specific question, the orbital period does not always decrease each time a comet approaches the Sun, but can increase, decrease, or stay the same depending on the details of the comet's outgassing during that particular close approach to the Sun. In addition to the period, other aspects of a comet's orbit that might change due to outgassing include the size of the orbit, how elongated the orbit is, and the tilt of the orbit relative to the rest of the solar system. So, these are all changes that astronomers will look for each time comets come close to the Sun. And in some cases, orbital changes in a small solar system object can be used by astronomers to infer the presence of outgassing when it may not be directly observable for some reason, such as in the case of the interstellar object 1I/2017 U1 'Oumuamua.

Aside from the effects of outgassing, comet orbits are also constantly changing simply due to the competing gravitational pulls of the major planets in the solar system. While the Sun's gravitational pull is by far the largest force affecting a comet's orbit, the comparatively weaker gravity of planets can still influence comet orbits in significant ways. As the largest planet in the solar system, Jupiter has the strongest influence after the Sun, but even smaller planets like Saturn, Mars, or Earth can produce small but noticeable changes in comet orbits, especially for comets that pass close to these worlds. As with outgassing, changes in a comet's orbit due to the combined gravitational influence of the major planets will depend on the exact details of those interactions, and orbital parameters can increase, decrease, or stay the same as a result. For most comets that don't pass extremely close to a planet, these changes are typically more subtle compared to those caused by outgassing, but can add up over time and so cannot be ignored by astronomers interested in tracking the orbits of comets over long periods of time.

Just like Earth, comets also spin on an axis (or sometimes tumble on multiple axes, like a wobbly, spinning top, but that's a topic for another day!) as they orbit the Sun. The time it takes to spin once — one "day" on a comet — is also called a period, but in this case, it is specifically called the rotational period. Just in case you're referring to this kind of period instead to the orbital period, the rotational period can also change due to cometary outgassing and for the same reasons. Again, as with orbital period changes, the rotational period can increase or decrease depending on the details of a particular comet's outgassing — mainly the positions, directions, and intensities of any cometary jets.

***Henry Hsieh***
*Senior Scientist, Planetary Science Institute, Honolulu, Hawaii*

**A VOLUME OF WHITE DWARF MATERIAL EQUAL TO A TEASPOON WOULD WEIGH SEVERAL TONS!**



BELOW: In 2019, astronomers announced they'd found direct evidence of white dwarfs solidifying into oxygen-carbon crystals, as depicted in this artist's illustration. After the white dwarf becomes completely frozen, it cools off and fades as it stops generating light. UNIVERSITY OF WARWICK/MARK GARLICK

**Q** | AFTER OUR SUN BECOMES A WHITE DWARF AND COOLS COMPLETELY, WHAT WILL BE LEFT?

***Richard Livitski***
*Seal Beach, California*

**A** | Our Sun will become a white dwarf in about 7 billion years. At that point, it will no longer produce energy through nuclear fusion, having exhausted its fuel (hydrogen and helium). Just like the embers of an abandoned campfire can only cool down with time, the white dwarf Sun will gradually become dimmer and cooler as it radiates its heat away into space.

The interior of this type of star is incredibly dense. To put this in perspective, a volume of white dwarf material equal to a teaspoon would weigh several tons! In such a condensed state, charged particles (oxygen and carbon nuclei) interact strongly due to the powerful electrostatic forces at play. Initially, these charged particles don't "feel" this force too much because they're moving quickly in all directions, thanks to the star's very high temperature.

But as the white dwarf Sun cools, the particles in its interior slow down. Eventually, they become so slow that they can't overcome the electrostatic interactions squeezing them from all sides — they become trapped. The interior of the white dwarf Sun will literally become a solid carbon-oxygen crystal. This freezing process, known as crystallization, is predicted to start roughly 3 billion years after our Sun becomes a white dwarf, or about 10 billion years from now.

Since diamonds are a solid form of carbon, it's often said that white dwarfs turn into diamonds. However, this isn't accurate — the matter inside a white dwarf is very different from a diamond. The interior of a white dwarf is not only much denser than anything found on Earth but also much hotter, even by the time the star freezes.

Once completely frozen, our white dwarf Sun will continue cooling for billions upon billions of years, slowly fading away as a dark, solid carbon-oxygen ball.

***Simon Blouin***
*Canadian Institute of Theoretical Astrophysics*
*National Fellow in Astrophysics,*
*University of Victoria, Victoria, British Columbia,*
*Canada*

## SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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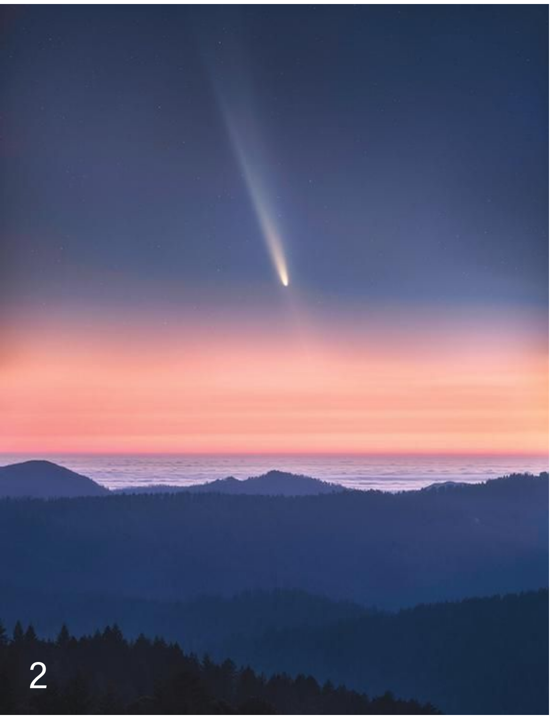
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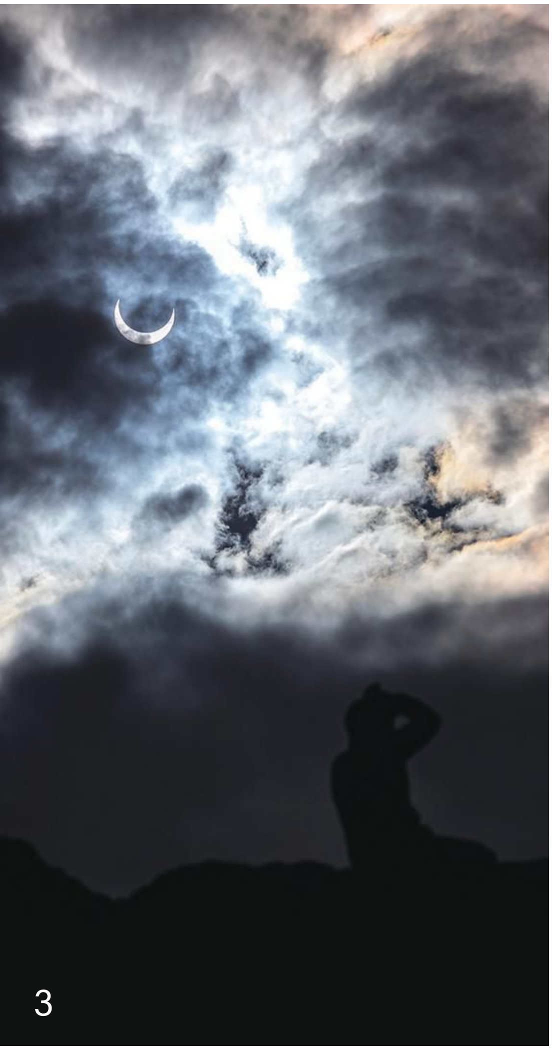
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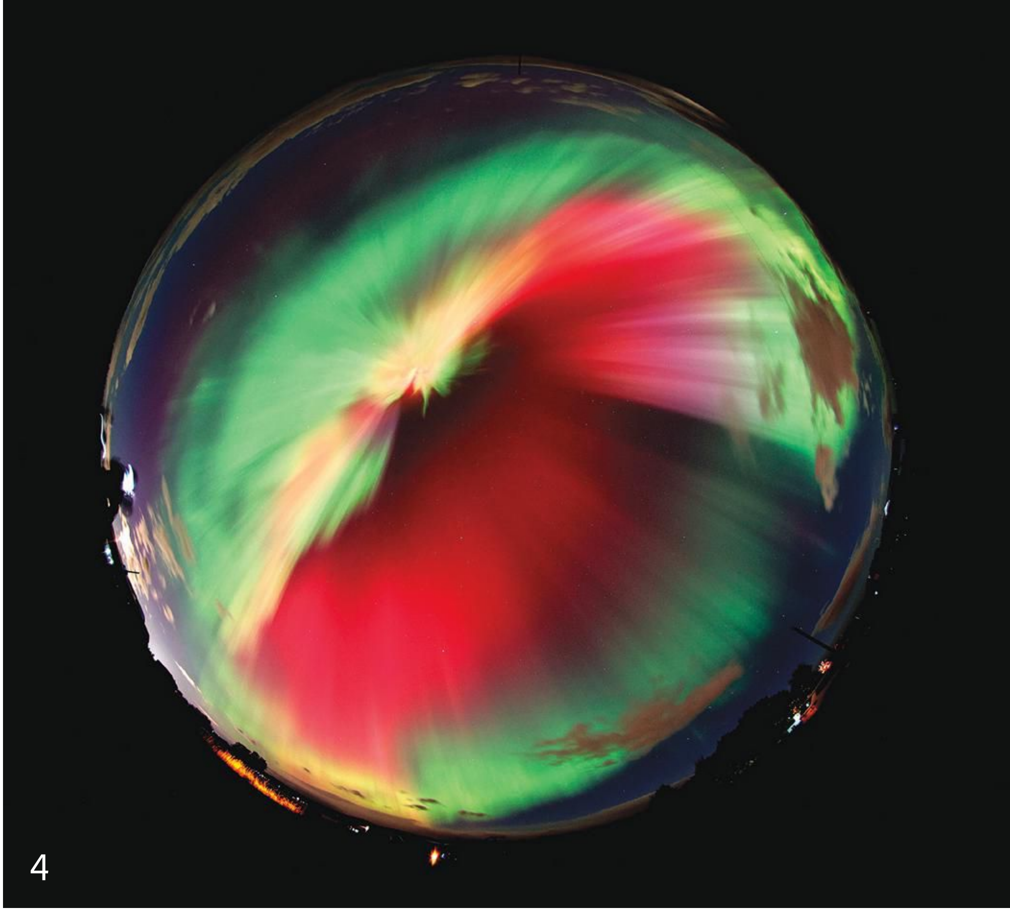
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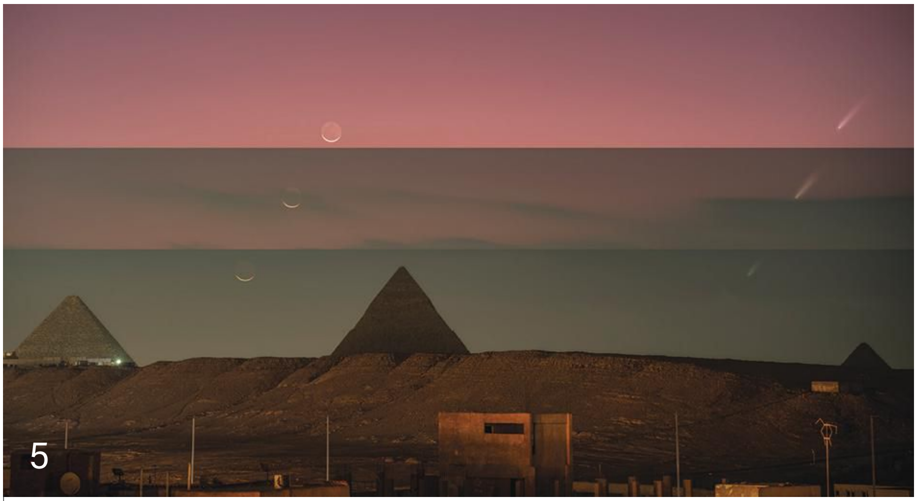
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**1. COMET OF THE YEAR**
Comet Tsuchinshan-ATLAS (C/2023 A3) delivered a stunning naked-eye spectacle. This shot was taken Oct. 14 from the slopes of Mount Etna in Italy at an elevation of 5,700 feet (1750 m). The photographer used a 2.4-inch refractor and a cooled CMOS camera to take 25 one-minute subframes. **▪ *Aldo Rocco Vitale***

**2. ABOVE THE FOG**
Tsuchinshan-ATLAS sets on the evening of Oct. 13 in this vista from an elevation of 2,800 feet (850 m) in California's Santa Cruz Mountains. The comet was captured with a Nikon mirrorless camera, a zoom lens at 135mm and f/3.2, and eight 10-second exposures at ISO 200. **▪ *Abhijit Patil***

**3. 2024'S *OTHER* ECLIPSE**
An eclipse watcher lines up a shot of the Oct. 2 annular eclipse in its partial phases from the rocks of Meseta del Asador in Santa Cruz Province, Argentine Patagonia. This image was taken with a Canon mirrorless camera and zoom lens at f/4.5 with an exposure time of 1/8,000 second at ISO 100. **▪ *Felipe Menzella***

**4. ALL-SKY AURORA**
Auroral reds and greens blanket the sky in this mosaic captured Oct. 10 from Quebec City with a Canon mirrorless camera and an 8mm fisheye lens at f/4 and ISO 1600. **▪ *Philippe Moussette***

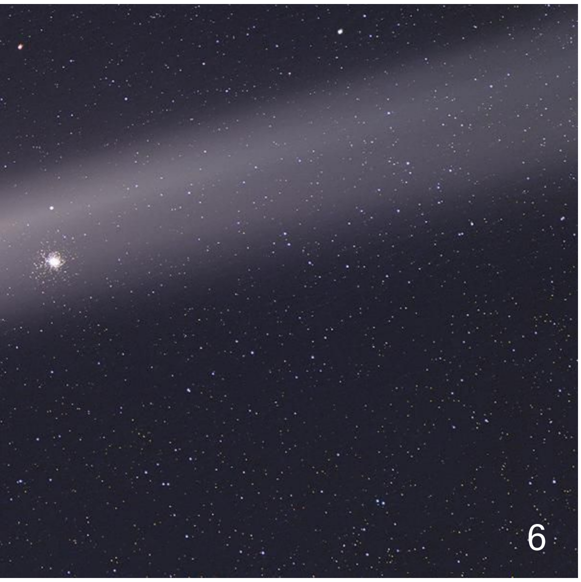
**5. THREE WONDERS**
Comet Tsuchinshan-ATLAS and a crescent Moon rise over the three main pyramids at Giza, Egypt, in this composite scene. Each layer consists of twenty-five 0.8-second subframes taken with a Sony astromodified mirrorless camera at ISO 800 and an 85mm lens at f/2.8. **▪ *Wael Omar***

### 6. NO TIME TO STOP

As Earth crossed through the plane of Tsuchinshan-ATLAS' orbit Oct. 14, the comet developed an anti-tail, captured here with a six-minute exposure on an 8-inch RASA, seeming to protrude forward from the comet's nucleus. An anti-tail is a perspective effect created when dust lingering in the comet's orbit appears to point toward the Sun. The star cluster at right is globular M5, also known as the Rose Cluster. ▪ ***Chris Schur***

### 7. AIR AND WATER SHOW

Aurorae reflect off Lake Huron from Collingwood, Ontario, during the G4-level geomagnetic storm of Oct. 10. The photographer used a Nikon DSLR to take a 10-second exposure at ISO 1000 and a zoom lens at 18mm and f/4. ▪ ***Tania Wood***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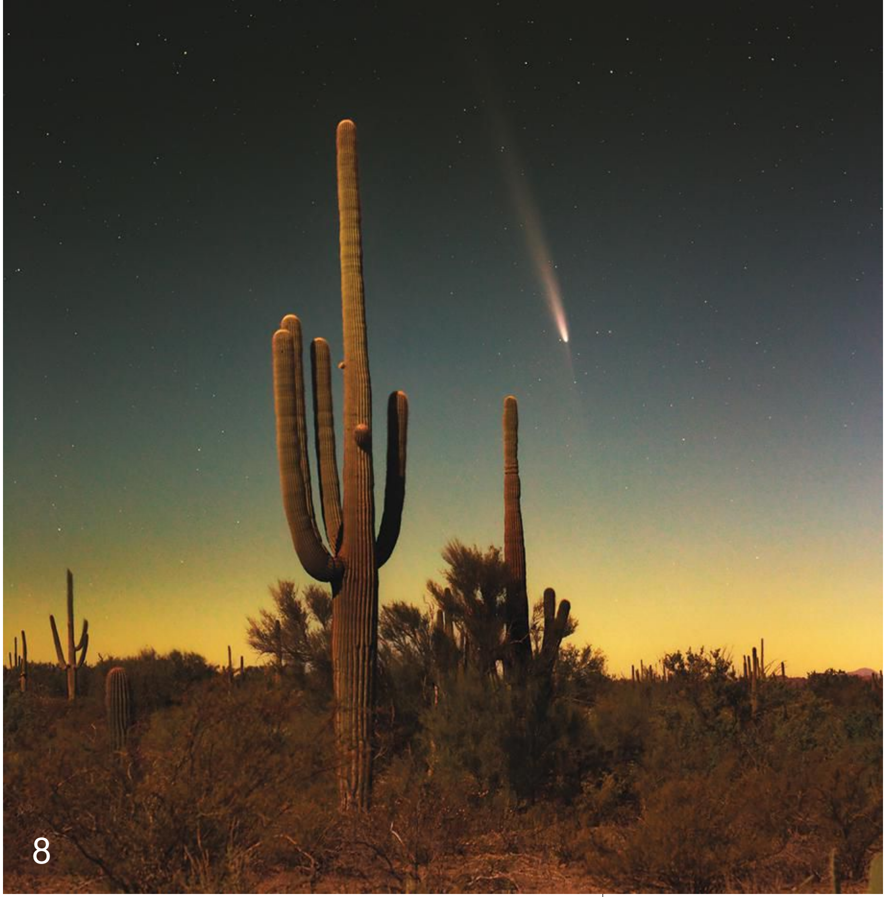
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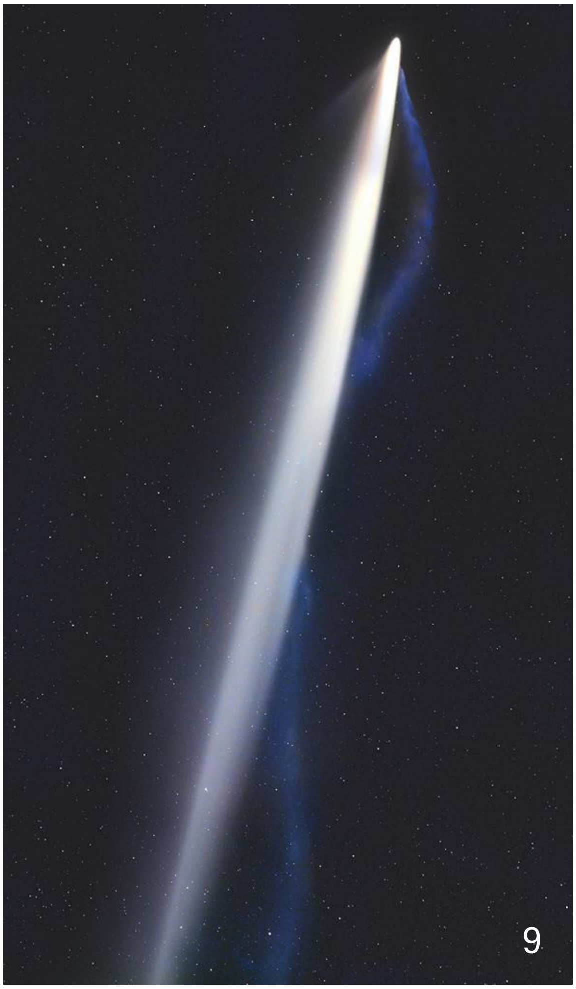
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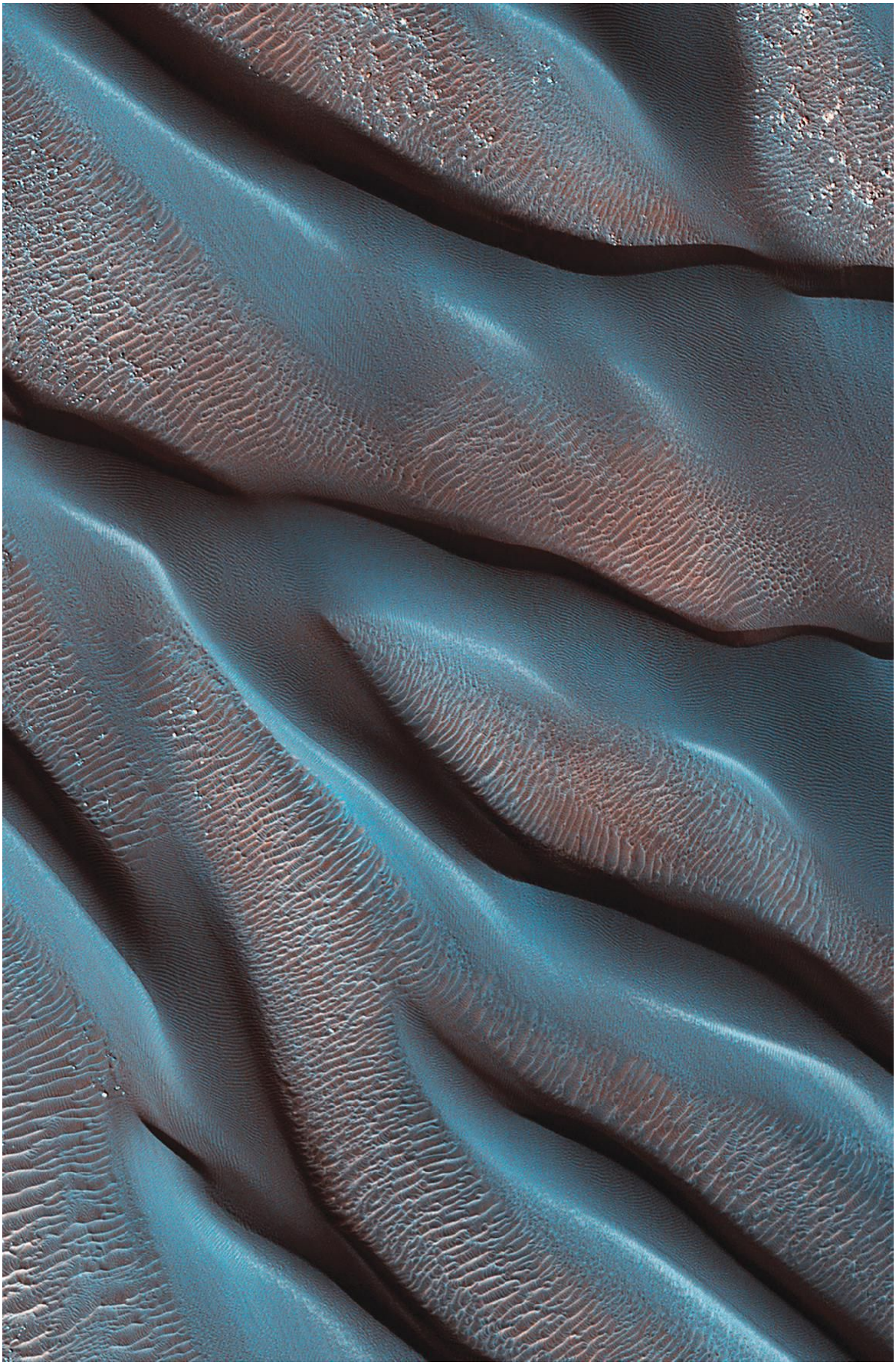
**8. HAPPY TRAILS**
Comet C/2023 A3 is pictured here Oct. 15 from Saguaro National Park near Tucson, Arizona. The image is a stack of 26 three-second shots with a 50mm f/1.4 lens at ISO 3200. • ***John Vermette***

**9. WAGGING ITS TAIL**
The twin tails of C/2023 A3 are on display here — the white dust tail and the blue ion tail, buffeted by gusts in the solar wind. The data for this LRGB image were taken with a combination of a Canon DSLR and an astronomical CMOS camera with 180mm and 200mm lenses. • ***Gerald Rhemann/Michael Jäger/Dennis Möller***

**SEND YOUR IMAGES TO: readergallery@ astronomy.com.** Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.



# BLUES FOR THE RED PLANET

Mars reaches opposition in mid-January, when it shines brighter than it has in 25 months. But that's a drop in the bucket compared with the 19 years the Mars Reconnaissance Orbiter (MRO) has spent studying the Red Planet. Since arriving in early 2006, MRO's High-Resolution Imaging Experiment (HiRISE) has captured more than 80,000 images of the planet's surface. This false-color view, taken near Mars' previous opposition, highlights an extensive area of migrating sand dunes in the Hellespontus Montes. The rugged mountain range lies on the western rim of the vast Hellas Basin. The steepest part of a dune marks its downwind side, revealing that the winds here typically come from the west (bottom) and drain into Hellas. With a diameter of 1,370 miles (2,200 kilometers) and a depth up to 5.6 miles (9 km), Hellas ranks among the solar system's largest impact basins.

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# SOUTHERN SKY

BY MARTIN GEORGE

## March 2025

# Spotlight on Mars and Jupiter

Two planets stand out in March's evening sky, but let's start our tour with a pair of lesser lights that hug the western horizon. Although **Venus** lies a respectable 30° from the Sun at the beginning of the month, it appears low in the sky. On the 1st, you can find the planet 5° high a half hour after sundown. Gleaming at magnitude –4.8, it's conspicuous if you have an unobstructed horizon.

The inner world's low altitude arises because the ecliptic — the Sun's apparent path across the sky that the planets follow closely — makes a shallow angle to the western horizon after sunset at this time of year. Venus also lies a few degrees north of the ecliptic, which compounds the problem. Its altitude improves slightly the closer you live to the equator. Try to grab a quick look through a telescope in early March. You'll see a disk measuring some 50" across with a wafer-thin crescent phase.

Venus quickly disappears in the twilight glare as it heads toward inferior conjunction March 23. It will return to view before dawn in April.

**Mercury** also lies in the evening sky, reaching a greatest elongation of 18° March 8. But it glows much more dimly than Venus and hangs even lower, making it nearly impossible to see from mid-southern latitudes. Like Venus, Mercury puts on a dramatically better show in April's morning sky.

Fortunately, two outer worlds make up for the poor performances of the inner planets. You can find **Jupiter** about one-third of the way from the northwestern horizon to the zenith as twilight comes to a close. Shining brilliantly at magnitude –2.2 in mid-March, you won't have any trouble identifying it among the background stars of Taurus the Bull.

Jupiter maintains a robust angular size — 38" at mid-month — and looks spectacular when viewed through any size telescope. The giant planet's banded atmosphere explodes with detail during moments of good seeing. And you'll easily spot the four bright Galilean moons as they change positions from night to night.

The ruddy glow of **Mars**, embedded among the background stars of Gemini, appears nearly due north in the early evening sky. Although the Red Planet dims from magnitude –0.3 to 0.4 during March, it still shines brighter than any of the Twins' stars.

The fading of Mars coincides with its increasing distance from Earth. This means the outer world also grows smaller. The planet's disk shrinks from 11" to 8" across during the month. Patient observers still should see some dark surface markings when the seeing steadies.

The final naked-eye planet, **Saturn**, reaches conjunction with the Sun on March 12 and remains out of sight all month.

A total lunar eclipse occurs March 14. Observers in South America and the eastern Pacific Ocean will have the best views. The eclipse's umbral phase lasts from 5h09m to 8h48m UT while totality runs between 6h26m and 7h32m UT. The final stages also will be visible from New Zealand and eastern Australia.

A partial solar eclipse takes place March 29, but it is strictly a Northern Hemisphere event.

## The starry sky

The famous Greek astronomer Hipparchus introduced the magnitude scale more than 2,000 years ago. He assigned the brightest stars 1st-magnitude status and the faintest 6th-magnitude status. In the mid-19th century, astronomers made this scale more rigorous by defining a difference of five magnitudes as corresponding to a factor of 100 in brightness.

In keeping with Hipparchus, observers generally consider stars of magnitude 6 the faintest visible to the unaided eye while the brightest (other than the Sun) are often called 1st-magnitude stars. Because of the strict mathematical definition now used, the brightest objects actually have negative magnitudes. Sirius, the most brilliant star in the night sky, has a magnitude of –1.46.

Even though a handful of stars possess negative magnitudes, many amateur observers loosely but conveniently consider any star at least as bright as magnitude 1.50 as a 1st-magnitude star. Because of rounding, a star of magnitude 1.51 would be relegated to 2nd-magnitude status.

Intriguingly, both the brightest and faintest of these so-called 1st-magnitude stars reside in Canis Major the Big Dog. This constellation passes nearly overhead early on March evenings, so now is a great time to examine the pair. I've already mentioned brilliant Sirius; Adhara (Epsilon [ε] Canis Majoris) marks the other end of the scale. It comes in right at magnitude 1.50, making it the 22nd and final 1st-magnitude star.

Within the past decade, the International Astronomical Union has instituted a significant change in the naming of stars. The organization now assigns names just to individual stars. This means that only one of the members in a binary or multiple system carries the name that may have been traditional for a long time. Epsilon CMa is such an example — a binary system hosting stars of magnitude 1.5 and 7.5. Only 7" separate the two and they differ in brightness by a factor of 250, making them tough to split in amateur instruments.

A noteworthy point about Adhara and its companion: They currently are receding from Earth at 27 km/s, so they are gradually fading. There eventually will come a time when Epsilon falls off the 1st-magnitude list.

# STAR DOME

## HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. March 1
9 P.M. March 15
8 P.M. March 31

Planets are shown at midmonth

## MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- ☐ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

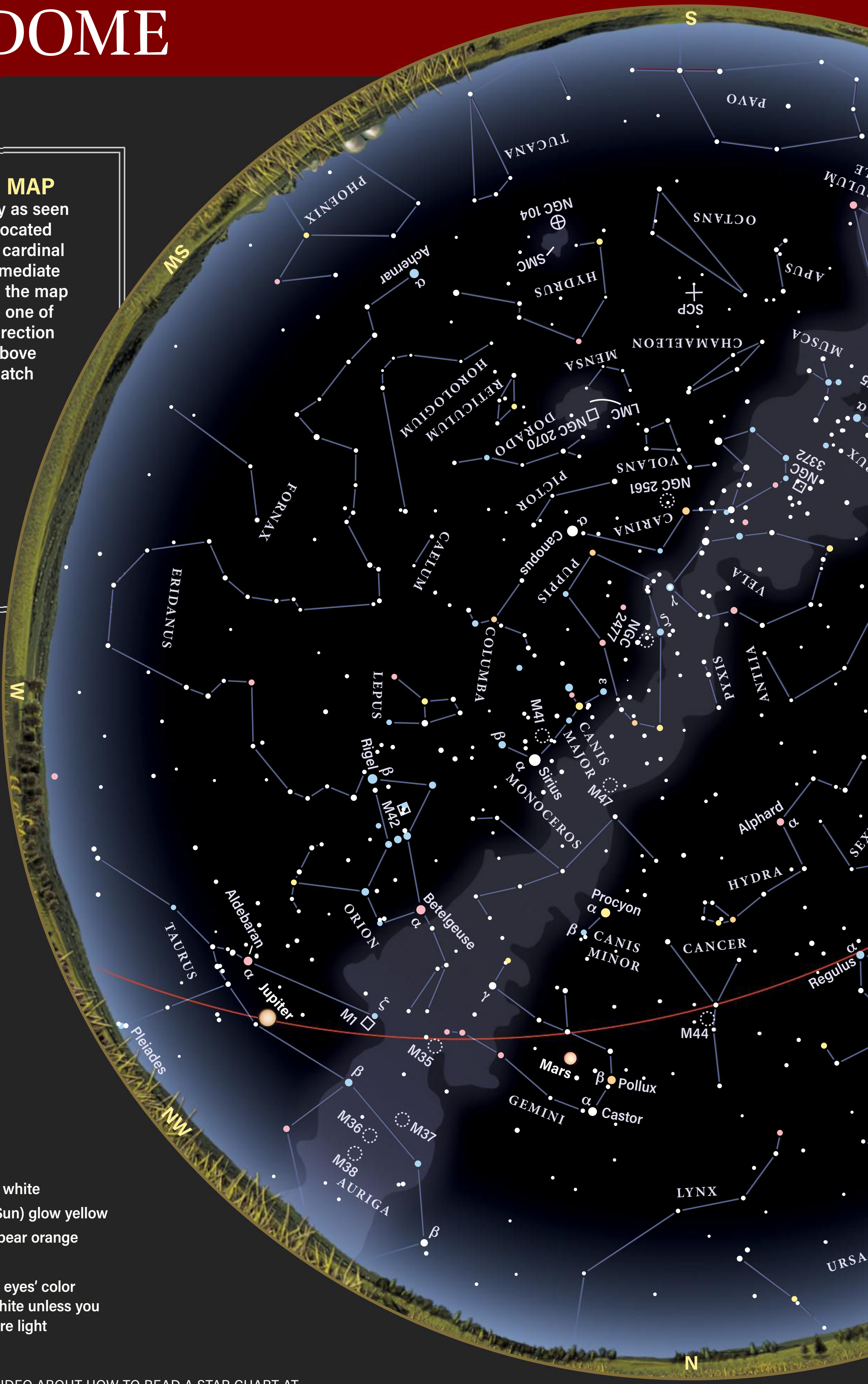
## STAR MAGNITUDES

| | | | |
|---|---|---|---|
| ● | Sirius | | |
| ● | 0.0 | • | 3.0 |
| ● | 1.0 | • | 4.0 |
| • | 2.0 | · | 5.0 |

## STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light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PAVO
TUCANA
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OCTANS
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Achernar
HYDRUS
APUS
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MUSCA
MENSA
HOROLOGIUM
RETICULUM
DORADO
NGC 2070
LMC
VOLANS
NGC 2561
NGC 3372
CARINA
PICTOR
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Canopus
FORNAX
CAELUM
PUPPIS
ERIDANUS
COLUMBA
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VELA
PYXIS
ANTLIA
LEPUS
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M41
CANIS MAJOR
β
α
Sirius
Rigel
β
M47
MONOCEROS
M42
Alphard
α
HYDRA
SEX
ORION
α
Betelgeuse
Procyon
α
β
CANIS MINOR
CANCER
Aldebaran
α
TAURUS
Jupiter
M1
ζ
γ
Regulus
α
M44
M35
Mars
β
Pollux
α
Castor
GEMINI
Pleiades
β
M36
M37
M38
AURIGA
β
LYNX
URSA

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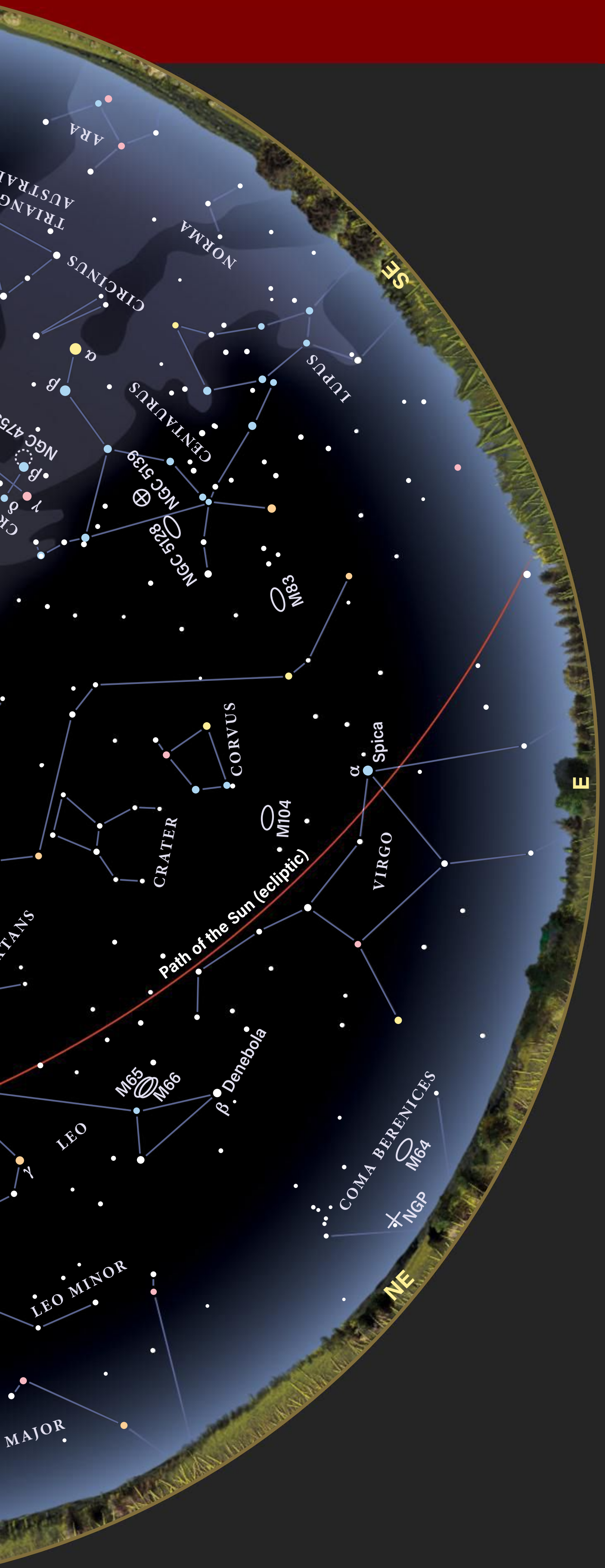
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NGC 4755
NGC 5139
NGC 5128
β
γ
δ
M83
CORVUS
α
Spica
M104
CRATER
VIRGO
E
Path of the Sun (ecliptic)
M65
M66
β
Denebola
LEO
γ
COMA BERENICES
M64
NGP
NE
LEO MINOR
MAJOR

# MARCH 2025

| SUN. | MON. | TUES. | WED. | THURS. | FRI. | SAT. |
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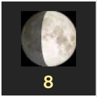
| 2 | 3 | 4 | 5 | 6 | 7 |  8 |
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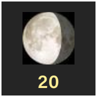
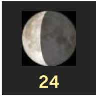
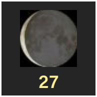
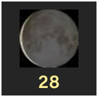
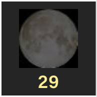
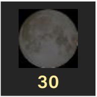
| 16 | 17 | 18 | 19 |  20 | 21 | 22 |
| 23 |  24 | 25 | 26 |  27 |  28 |  29 |
|  30 | 31 | | | | | |

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**

## CALENDAR OF EVENTS

**1** The Moon passes 0.4° south of Mercury, 4h UT
The Moon passes 1.6° north of Neptune, 9h UT
The Moon is at perigee (361,964 kilometers from Earth), 21h21m UT
The Moon passes 6° south of Venus, 23h UT
**5** The Moon passes 5° north of Uranus, 4h UT
**6** The Moon passes 6° north of Jupiter, 12h UT
First Quarter Moon occurs at 16h32m UT
**8** Mercury is at greatest eastern elongation (18°), 6h UT
**9** The Moon passes 1.7° north of Mars, 0h UT
Mercury passes 6° south of Venus, 11h UT
**12** Saturn is in conjunction with the Sun, 10h UT
Asteroid Flora is at opposition, 22h UT
**14** Full Moon occurs at 6h55m UT; total lunar eclipse
Mercury is stationary, 21h UT
**16** The Moon passes 0.4° south of Spica, 20h UT
**17** The Moon is at apogee (405,754 kilometers from Earth), 16h37m UT
**19** Neptune is in conjunction with the Sun, 23h UT
**20** March equinox occurs at 9h01m UT
The Moon passes 0.5° south of Antares, 17h UT
**22** Last Quarter Moon occurs at 11h29m UT
Asteroid Juno is stationary, 18h UT
**23** Venus is in inferior conjunction, 1h UT
Asteroid Vesta is stationary, 5h UT
**24** Mercury is in inferior conjunction, 20h UT
The Moon passes 0.9° south of Pluto, 21h UT
**28** The Moon passes 9° south of Venus, 14h UT
**29** New Moon occurs at 10h58m UT
**30** The Moon is at perigee (358,128 kilometers from Earth), 5h25m UT
Venus passes 10° north of Saturn, 6h UT

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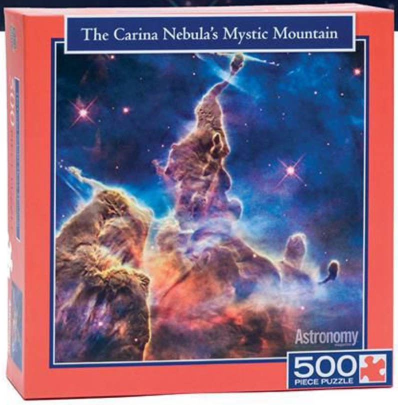
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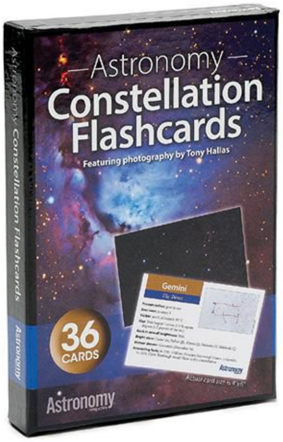
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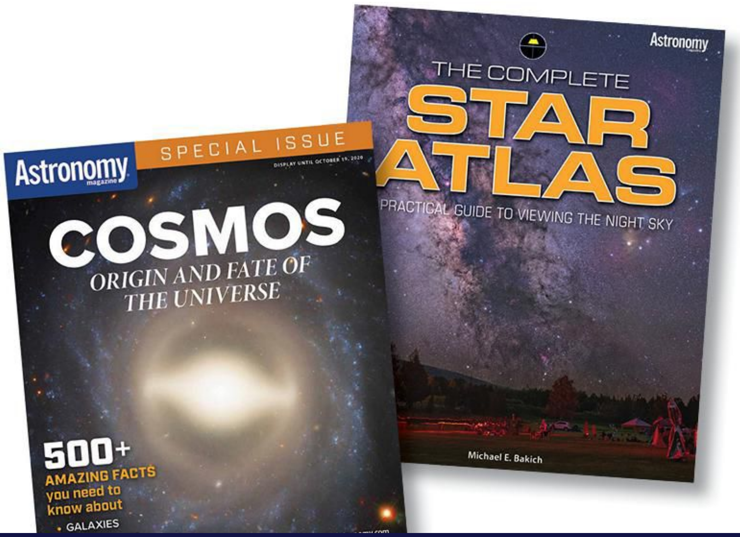
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